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A PRACTICAL GUIDE

TO THE

TESTING

OF

INSULATED WIRES AND CABLES.

BY

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PREFACE.

THE following pages contain a reprint of a series of articles which appeared originally in *The Electrical Engineer*. The articles having been favorably received by the readers of that journal, it is thought that their collection in complete and convenient form will be acceptable to that large proportion of the electrical profession engaged in the construction and maintenance of overhead and underground wires.

The main idea running through this little work is to present in clear and practical form the ordinary every-day work of the testing-room, in other words, the rudiments of wire and cable testing, with a view to furnishing to the workers in the great fields of telephony, telegraphy, electric lighting and electric railroading a concise guide to the manipulation of a set of testing instruments.

It goes without saying that references have been occasionally made to the standard work on this subject, Kempe's "Handbook of Electrical Testing;" and the same writer's "Electrical Engineer's Pocket-book," has also, from time to time been referred to.

The author's acknowledgments are due to Mr. E. H. Lyon for assistance in the preparation of the original diagrams, which materially help to explain the text.

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A PRACTICAL GUIDE
TO THE
TESTING OF INSULATED WIRES AND CABLES.

CHAPTER I.

The Principles of Testing.

THE use of high-class insulated wires, both in the form of underground and overhead cables, and, indeed, for all classes of electrical work, has of late years increased to such an extent in this country that the necessity for careful and systematic testing has grown proportionately, and an opinion exists that a simple and practical description of the methods and apparatus employed in making tests for insulation resistance, inductive capacity and conductor resistance, would probably be welcome to those who find it necessary to include such work in the catalogue of their daily duties.

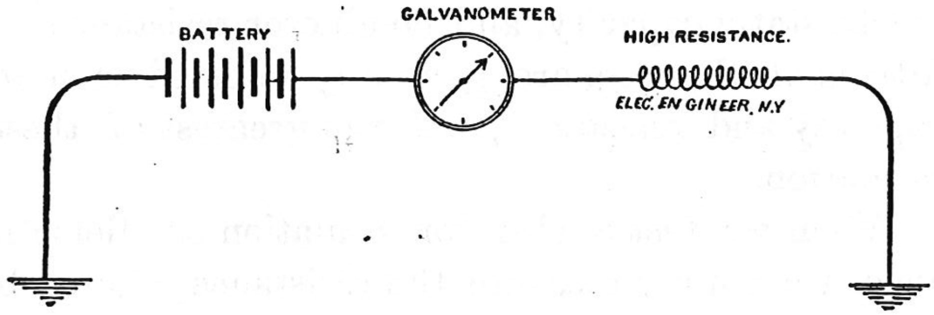

FIG. 1.

It is not a difficult matter for anyone who exercises a little ordinary care to make the usual tests referred to if the instruments are properly set up for him and nothing goes wrong; but it is not unusual to find a man take very kindly to working in this way and yet not have more than a very vague idea of what he is actually doing, and why certain manipulations of the battery and keys give certain results, and certain other manipulations give quite distinct results. For this and other reasons, in preparing these articles I have decided to confine myself strictly to the most simple methods (which, be it stated, are those most generally used), and to describe them very fully, avoiding mathematics as far as possible. If, after following me through these first courses in the science of electrical testing, any budding expert has acquired an appetite for stronger meat and more of it (as I sincerely hope he will), let him turn to Kempe, where he will find it in abundance.

A wire or cable to be used for telegraphic or telephonic purposes is submitted to three distinct tests, in order to determine its insulation or dielectric resistance, inductive or electrostatic capacity, and conductor resistance. The conditions of the wire are generally referred to as insulation, capacity and resistance, and the greatest of these three is insulation.

When we test a wire for insulation or dielectric resistance, we simply measure the resistance offered by the insulating covering to the passage of a current of electricity from the conductor to the ground. This is done by charging the wire from a powerful battery, the distant end of the wire being free, or disconnected, and the current being allowed to pass through a delicate galvanometer before entering the wire or cable. Now, it is clear that as the far end of the wire is not connected to anything, the only escape for the current is across the insulation to ground. A certain amount of current escapes in this way, causing a deflection of the galvanometer needle. By comparing this deflection with that obtained by allowing the current to flow to ground through a known resistance we arrive at the resistance of the insulation.

It stands to reason that the first operation is to obtain this standard deflection with which the deflection given by the cable is to be compared ; this is called "taking the constant of the galvanometer," and the deflection obtained is generally termed the *constant.*

Fig. 1 shows diagrammatically the arrangement of instruments for getting the constant. One pole of the battery is connected to earth, and the other to one terminal of the galvanometer, the second terminal of which is joined to one side of the high resistance, the other side of the high resistance going to earth.

Here we have a complete circuit through the galvanometer coils and high resistance, and the galvanometer needle is deflected over a certain number of divisions of the scale, and remains steady at that point as long as no variation takes place either in the strength of the battery or in the amount of resistance in circuit. In this way we know how much the galvanometer needle will be deflected when a certain resistance is offered to the current from the battery. The deflection is noted and constitutes the galvanometer constant. By comparing the deflection obtained from the cable with this deflection, the insulation resistance of the cable, in terms of the resistance used in taking the constant, is arrived at. In practice, as we shall see further on, the galvanometer is always shunted when taking the constant, so that only a fractional part of the current shall pass through the galvanometer coils, but for the sake of clearness the shunt is not shown in the diagram.

In Fig. 2 the cable is substituted for the high resistance

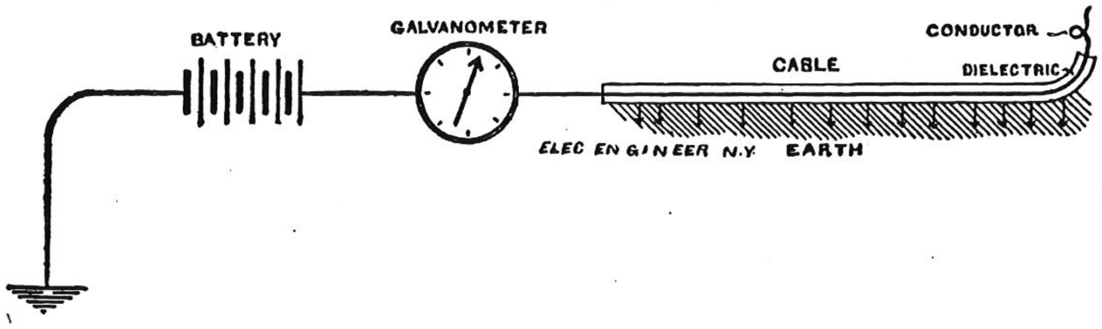

FIG. 2.

shown in Fig. 1. The cable is charged up from one end by the battery, the far end being free, and the current passes to earth across the dielectric, much in the same way as it would through the coils of the high resistance. A slight leakage of current takes place along the whole length of the cable, and the longer the cable the more leakage there will be. The passage of the current through the insulation to ground will be more readily understood if the dielectric be considered, as it really is, merely a conductor of very high resistance, one side being in close contact with the earth and the other side connected by the cable conductor, which, of course, makes perfect contact with the dielectric along its whole length. In this case the dielectric merely takes the place of the high resistance, the conductor of the cable being the connecting wire. It is plain, therefore, that the leakage will vary directly as the length of the cable, which constitutes the cross-section of the conductor whose resistance we are measuring; the longer the cable, the greater the cross-section of the conductor and the lower its resistance; while, if the cable is short, the cross-section of this high resistance conductor will be correspondingly decreased, causing a proportionate increase of resistance. The length, of course, is always the same, being merely the thickness of the dielectric.

The simplest method of measuring the electrostatic capacity of an insulated wire or cable is by comparing the charge of electricity which it is capable of receiving, with the charge of a standard condenser of known capacity. A condenser is practically a Leyden jar in a small space, and consists of a number of plates of tinfoil alternated with plates of mica or paraffined paper. On connecting one pole of a battery to one set of the tinfoil sheets, the other pole of the battery and the other set of tinfoil sheets being connected together or to earth, the condenser is charged to its full capacity, the charge on one set of plates inducing another of opposite sign on the other set. This arrangement is shown diagrammatically in Fig. 3.

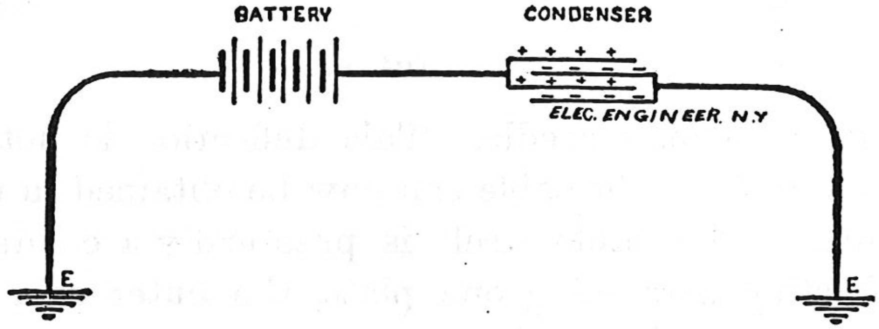

FIG. 3.

If now we connect the terminal of the condenser which was first connected to the battery, to earth through a galvanometer, as in Fig. 4, the charge is released, and a discharge to earth takes place, producing a sudden throw of the galvanometer needle. This deflection is noted. The discharge from the cable can now be obtained in the same manner. The cable itself is practically a condenser, the conducting wire being one plate, the outer sheathing the other, and the dielectric the separating medium. If, as in Fig. 5, we connect the battery to one end of the conductor, the far end being left free, the cable will be charged up in the same way as the condenser. After charging for a few seconds the battery is disconnected and the cable is allowed to discharge to earth through a galvanometer, as shown in Fig. 6. The deflection produced is noted, and dividing it by the deflection obtained by the discharge of the standard condenser, we arrive at the capacity of the cable in terms of the capacity of the standard condenser.

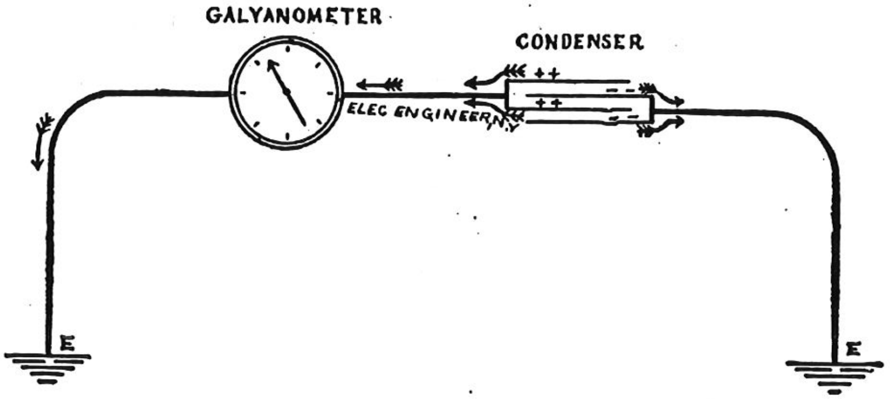

FIG. 4.

In Fig. 7 is shown diagrammatically the method of measuring the resistance of a conductor, by means of the Wheatstone bridge. One pole of the battery is connected to the centre of the bridge at A, the other pole being put to earth. The conductor is connected to one end of the bridge at C; and to the other end, at B, is connected an adjustable resistance; both the conductor and the adjustable resistance being also connected to earth. Between B and C is placed the galvanometer. The current from the battery divides at A and goes to earth partly by way of A C and the cable, and partly by way of A B and the adjustable resistance. It is obvious that if the branches between A and the earth are not of equal resistance, there will be a difference of potential between B and C, and, there being a connecting path between them by way of the galvanometer, a certain amount of current will pass from one point to the other, producing a deflection on the galvanometer.

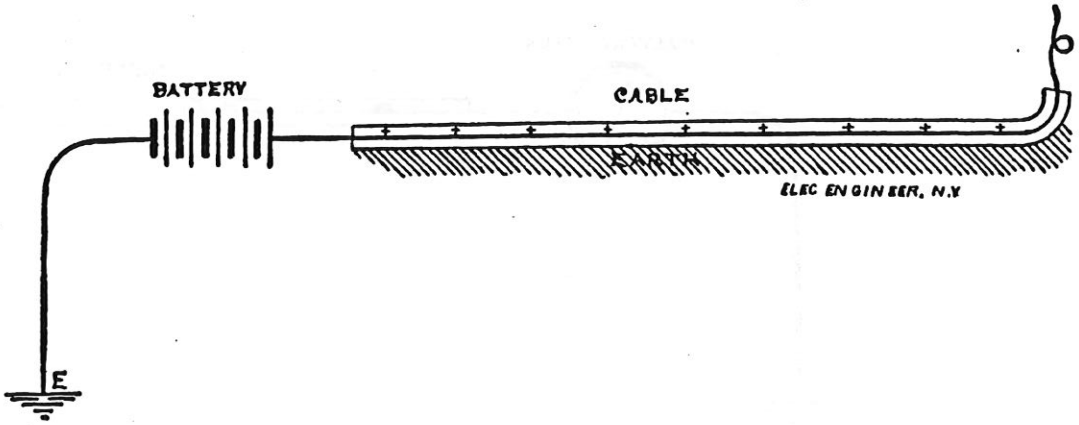

FIG. 5.

By consulting the diagram, the aptness of the term, bridge or balance, is easily noticeable. Supposing the arm B A C to be the beam of a balance, and the galvanometer to be the pointer, it is obvious that the pointer will only be at zero when the objects attached to B and C are exactly equal, assuming the two arms to be of equal value.

If a deflection is produced on the galvanometer it is a si that there is a difference of potential between B and

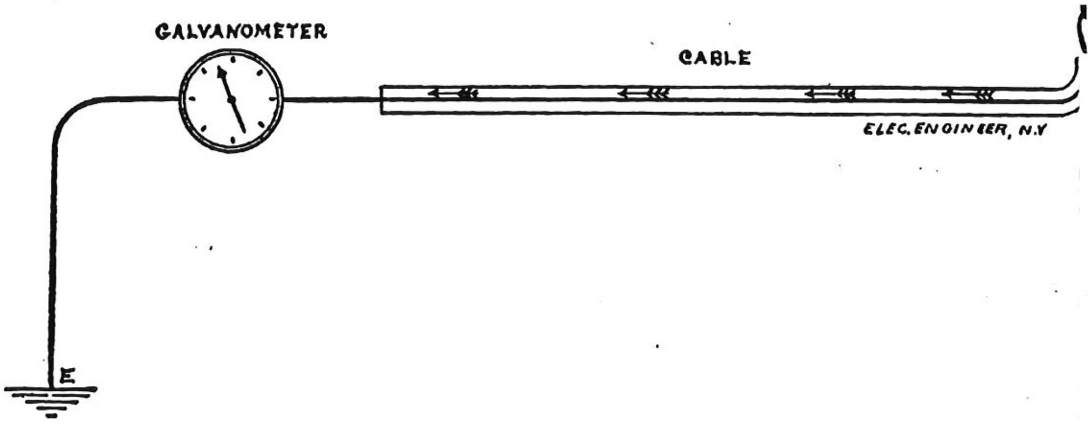
GALVANOMETER
CABLE
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FIG. 6.

and that consequently the resistance connected to B is n equal to that connected to C. As the latter is the fixe resistance to be measured, the adjustable resistance mu be altered until there is no deflection on the galvanomete This shows that the battery current dividing at A flows i equal proportions towards B and C, producing equal pote

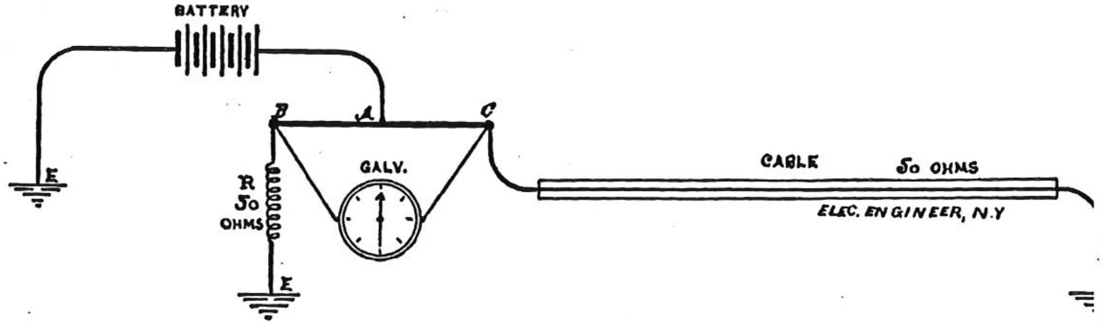
BATTERY
B
A
C
E
R
50
OHMS
GALV.
CABLE
50 OHMS
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FIG. 7.

tials at those points; consequently, the resistances attache to B and C are now equal, and the resistance of the cabl is ascertained by observing the amount of resistance in th adjustable coils.

CHAPTER II.

Galvanometers.

HAVING seen just what is done in each test, let us now proceed to examine the actual instruments required for carrying them out and the methods of connecting up the instruments in practice.

GALVANOMETERS.

The most important instrument in any testing outfit is the galvanometer, as it is by means of the indications of the galvanometer that comparisons are made between the wires or cables to be tested and the standard instruments, such as high resistances, condensers and resistance coils.

The galvanometer usually employed for fine testing is that known as the Thomson reflecting galvanometer ; this instrument is made in a great number of different forms, of which it will be necessary for our purposes to describe only the two or three which are most used in general work.

The usual form of astatic reflecting galvanometer is shown in Fig. 8. It consists of a hard rubber base mounted on three leveling screws and provided with either a circular level or two short spirit-levels placed at right angles to each other, so that the instrument may be accurately leveled when set up. Mounted perpendicularly on the base are the four galvanometer coils, the two at the rear being fixed and the front two hinged, so that the astatic needle system can be removed if necessary. At the top of the brass frame to which the coils are attached is a hole into which fits a small brass stud. From the lower part of this stud is suspended, by a single fibre of raw silk, the

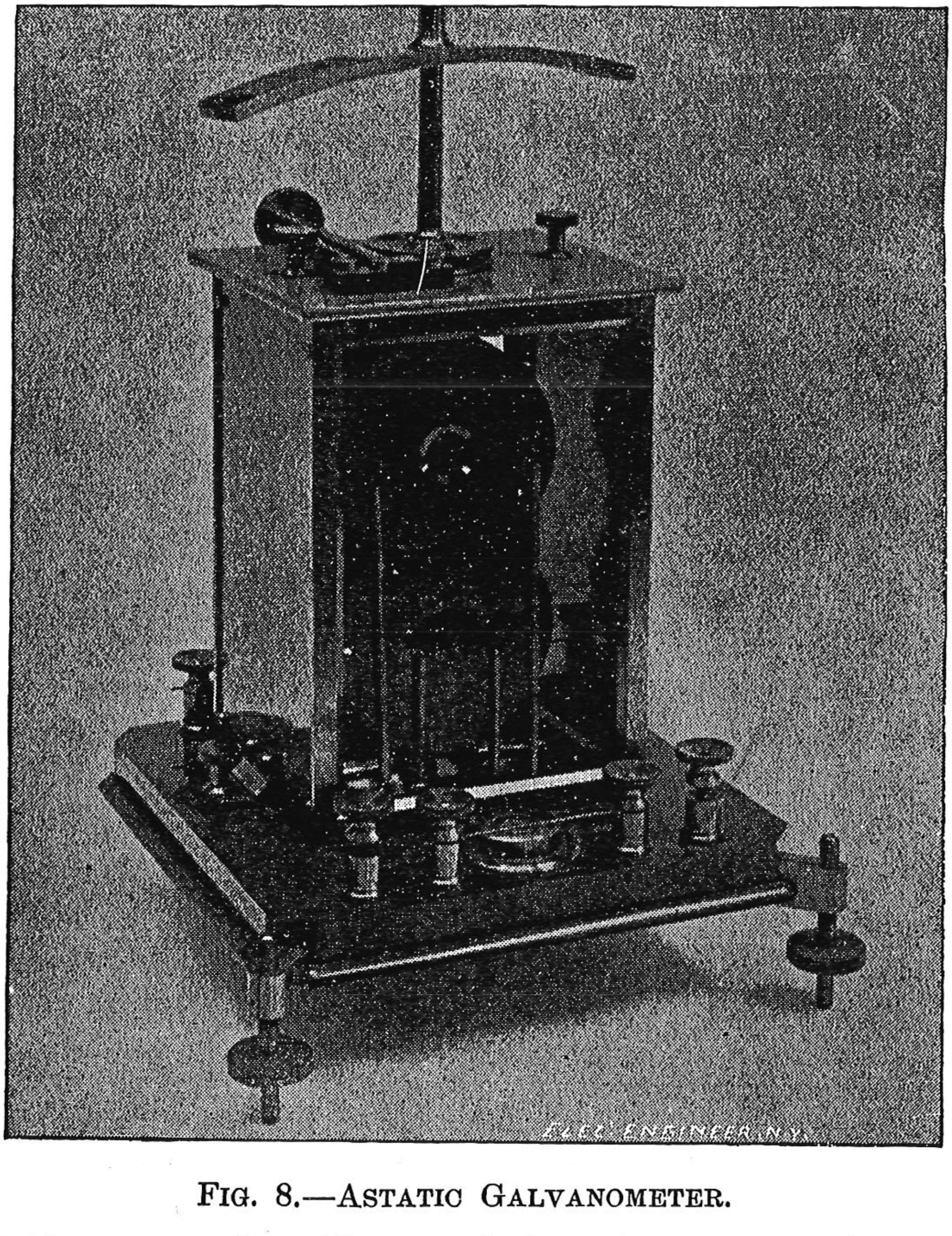

FIG. 8.—ASTATIC GALVANOMETER.

astatic system of needles, consisting of two small pieces of steel, strongly magnetized, connected together by a fine aluminum wire, the N pole of the lower needle being beneath the S pole of the upper. By this arrangement the directive force of the earth's magnetism is minimized and greater sensitiveness obtained.

To the upper needle is attached a small mirror by means of which a ray of light is reflected back to a graduated scale; at right angles to the lower needle a small vane is fixed in order to check the swinging of the needles and bring them to rest quickly. The brass stud from which the needles are suspended can be lowered so that the vane rests on the coils; all strain is then taken off the silk fibre and the instrument can be moved without risk of breaking the fibre, but it should never be carried about without taking this precaution.

In raising the brass stud care should be taken to merely press it gently upward by squeezing the fingers in between the head of the stud and the frame; on no account *twist* the stud, as in this way torsion would be put into the fibre and trouble from unequal deflections on opposite sides of the scale would be the result.

The coils are enclosed by a case of brass with plate glass front and back, or by a glass cylinder.

To the top of the case is fitted a rod which supports a very weak permanent magnet by which the needles may be directed so as to bring the spot to any part of the scale; by lowering or raising the magnet on the rod the sensitiveness of the needle may be diminished or increased. For fine adjustments the rod and magnet can be turned together by a tangent screw on the top of the case.

For reading the deflections of this galvanometer a lamp and scale are provided, the light from the lamp being focussed on the mirror of the galvanometer, which reflects back a spot of light on the scale. The scale is usually of cardboard and is ruled with 360 divisions on each side of the zero. The spot of light may be either a fine narrow streak covering about one division of the scale, or a round spot with a black line across the centre, the line being produced by a fine wire stretched across the orifice behind the lens. For a cardboard scale the round spot with the black line is preferable, as the part of the scale on each side of the deflection is illuminated and readings can be made with greater comfort to the observer. Many prefer using a ground glass scale, which is ruled in the same manner as the cardboard scale. The lamp in this case is placed at the side of the scale and the beam of light is reflected to the galvanometer by means of a small mirror mounted on an arm having a universal joint. The observer stands behind the scale, instead of in front of it, and the "spot" appears to him as a line of light on the dark ground glass. With this kind of scale a capital spot can be obtained by using as the source of light an incandescent lamp with a very straight filament, and either getting the two legs of the filament in line, or, better still, so arranging the lamp that one leg of the filament only is reflected by the mirror. In this way a sharply defined line of light is obtained and very close readings can be made.

The advantages of the ground glass scale are that the spot can be seen plainly even though the testing room is very light, and, that as the observer has not to place himself at one side of the scale but directly behind it, he is in a better position for manipulating the instruments and can allow himself more sea-room in setting them up. About the only disadvantage is that it is necessary to follow the movements of the spot pretty closely, as it is almost invisible except from exactly behind the part of the scale to which it is deflected.

In setting up the galvanometer, care should be taken to select a steady place. In cable factories a masonry pedestal with a solid foundation, and not joined to any other part of the building, is generally constructed for the purpose, and in this way the galvanometer is kept free from vibration or jarring. In many places, however, such facilities are not obtainable and it is often necessary to set up the instruments in a room on an upper story, and in a building where heavy machinery is working almost continually. It then becomes necessary to resort to various devices to free the galvanometer from the effects of the vibration of the building. If the building is of very solid construction, a substantial shelf, firmly fixed to the wall, should provide a steady place; if vibration is still felt, a sheet of rubber or some thick rubber rings should be placed on the shelf and above this a heavy slab of lead, the galvanometer being placed on top.

The most sightly way of arranging this is to have a neat wooden case for containing the lead, which may be run in melted or in the form of fine shot. If this plan does not answer, a tray of sand may be substituted for the rubber, the weight being placed on the sand. The last expedient of all is to suspend the galvanometer by means of springs.

The usual plan is to place the galvanometer on a tray hung from a bracket by four coiled brass springs about three feet long. The tray is damped either by means of vanes working in air-tight boxes below, or by fixing brushes at the sides, the brushes just bearing against the edges of the tray. By this arrangement all vibration may be got rid of, but great care is needed in moving about not to touch the springs, or, in fact, any part of the hanging tray, as the least jar is sufficient to set the needle dancing for some minutes.

When the galvanometer is set up it should be placed on a dry surface and the hard rubber base should be clean and dry ; if there is any likelihood of moisture being present in the air, small plates or cups of hard rubber should be put under the leveling screws in order that the instrument may be thoroughly insulated. When possible it is best to place the galvanometer facing west, the needles being north and south ; but it is often necessary to have it face east, according to the position of the room set apart for testing.

A good astatic galvanometer will not be affected by magnetic disturbances if the disturbing influences are more than a very short distance away, but if magnets, or iron tools, etc., are being constantly moved about within ten or twenty feet of the galvanometer, some sort of magnetic shield will be required to prevent the oscillations of the needle which would otherwise result. The most effective magnetic shield is an old iron safe, a hole being cut in the door large enough to allow of the free transmission of the beam from the mirror when the needle is deflected to its fullest extent. A box of sheet iron will be found more manageable than a safe and may be suspended from springs in the manner described above, thus getting rid both of vibration and magnetic disturbance.

The principal objection to the use of an iron shield completely enclosing the galvanometer is the inconvenience in altering the height or position of the directing magnet. The best combination of magnetic shield and hanging tray is to have the iron box supported on a shelf, and the galvanometer suspended by means of springs passing through holes in the top of the box. To obviate the difficulty referred to above, of altering the position of the directing magnet without disturbing the galvanometer, the rod supporting the magnet is fixed to the under part of the top of the iron box, and the tangent screw is prolonged so that the milled head is outside the box. In this manner the magnet can be raised or lowered without touching the galvanometer, and the direction of the magnet can be altered by means of the screw without opening the box. Such an arrangement as this is a very efficient preventive both for magnetic and mechanical disturbances, and it has the advantage that the parts of the suspended spring contrivance which would ordinarily be exposed to accidental jarring are rendered inaccessible by being enclosed in the iron box.

The regular pattern astatic reflecting galvanometer is generally wound to about 8,000 or 10,000 ohms resistance, and sometimes even higher. The fine silk-covered wire is wound on four separate bobbins, as already described; the ends of the coils are led to eight terminals on the base plate, four in front and four in the rear, and, by varying the connections between these terminals, the combined resistance of the four coils may be varied. A diagram of these connections is always supplied by the manufacturer, but for general work it is rarely, if ever, necessary to use the coils in any other manner than all in series, so as to obtain the maximum resistance.

CHAPTER III.

Galvanometers.—(Continued.)

A VERY convenient form of galvanometer, illustrated in Fig. 9, is the tripod astatic. This galvanometer is much less expensive than the square pattern, and also more adapted for carrying about, as it can be packed in less space, making it a very useful instrument where much outside work has to be done. It has only two coils, which are generally wound to a resistance of about 5,000 ohms. The mirror with the upper needles is suspended in the centre of the coils, and the lower needles with the vane hang just below the coils; the terminals, of which there are two only, instead of eight, are placed at the rear of the case. This form of galvanometer is not so sensitive, of course, as the pattern first described, but if properly set up will give very good results, and is amply sufficient for all ordinary work, with the exception, perhaps, of testing very short lengths of heavily insulated cable. A little extra care is required in setting up the galvanometer, as it is not provided with a spirit level; if no small level is at hand to assist the eye, the best plan is to watch the mirror while adjusting the leveling screws until it hangs exactly in the centre of the coils.

Another form of reflecting galvanometer, much used for outdoor work and carrying about from place to place, is the portable dead-beat instrument, illustrated in Fig. 10. The dead-beat arrangement was invented by Sir Wm. Thomson, to do away with the inconvenience of waiting for the needle to cease oscillating before taking up a settled

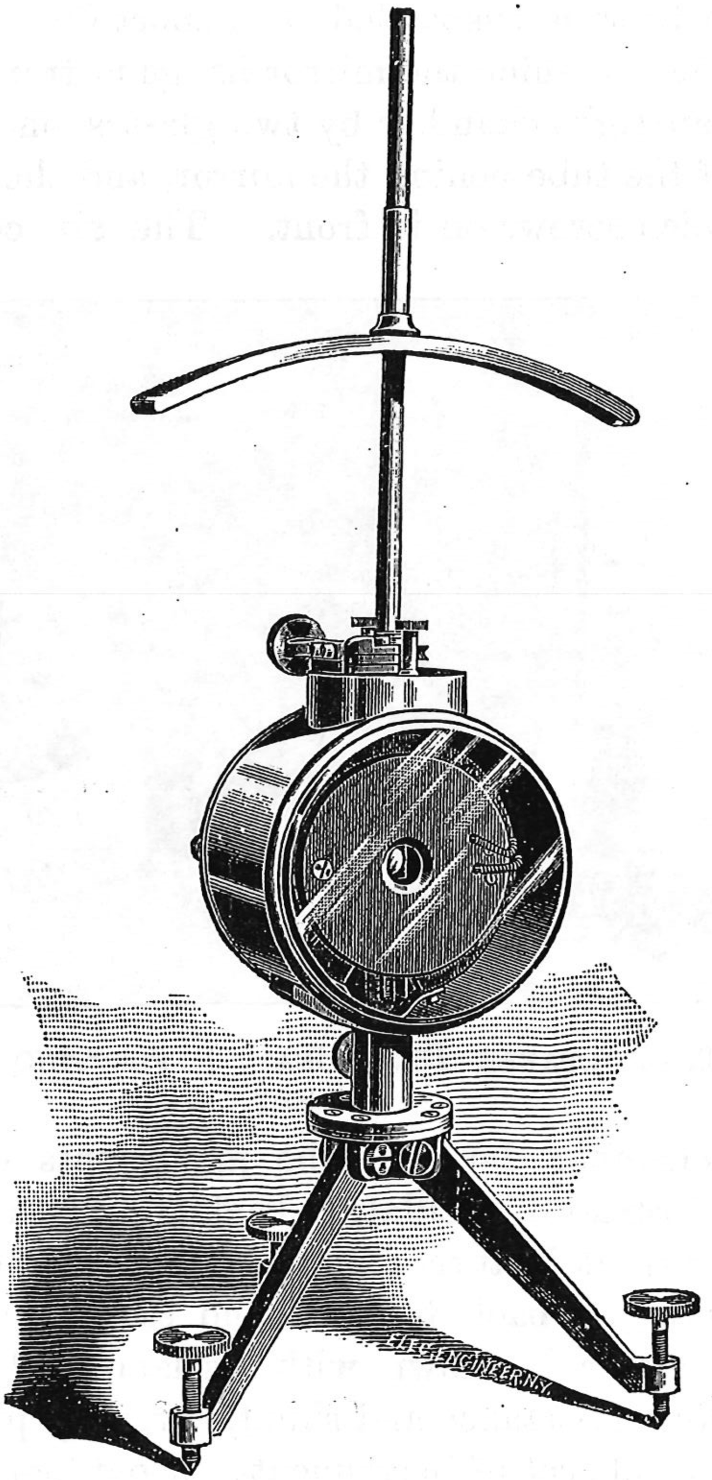
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FIG. 9.—TRIPOD ASTATIC GALVANOMETER.

position on the scale. The mirror with the small needles at the back is suspended by a short fibre in a brass tube; the space in which the mirror hangs is transformed into a small air-tight chamber by two glasses, one set in the main part of the tube behind the mirror, and the other in a small cap which screws on in front. The air confined in this small chamber dampens the movements of the mirror, which, instead of oscillating back and forth for some time when current is turned on and off, turns steadily to a certain angle, or back to zero, and stops dead. The small galvanometer is shown with its lamp and scale and combined high resistance and shunt, forming part of a compact portable set of instruments for outdoor testing.

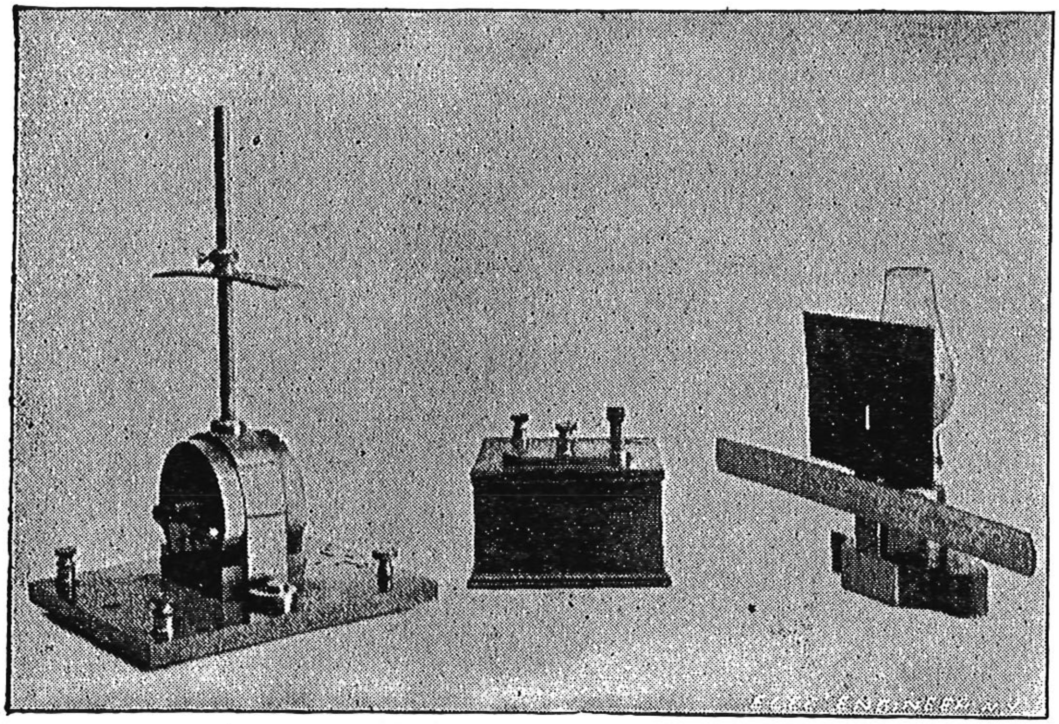

FIG. 10.—PORTABLE DEAD-BEAT REFLECTING GALVANOMETER SET.

This form of galvanometer is by no means to be recommended for general work; it is not sensitive, and the readings, under certain conditions, are not any too accurate. Magnetic disturbances affect it very considerably, even if the moving iron be some distance away from the galvanometer. To overcome this difficulty, which is present with a non-astatic instrument almost everywhere except in the open country, the magnetic shield, shown in Fig. 11, has been designed and has proved very useful. It consists simply of a hollow case of tin plate made in two sections so as to enclose the galvanometer coil, and filled up with iron filings. This arrangement forms a very efficient screen for magnetic disturbances under most circumstances, although in some cases it has failed to keep the needle from being affected.

SHUNTS.

The most important accessory to a galvanometer is, of course, the shunt. This consists of a set of resistance coils placed in a suitable box or case provided with terminals by means of which it may be connected with the galvanometer and the source of current. The coils form a path outside the galvanometer for the current, which will be divided between the shunt and the galvanometer coils in inverse proportion to their resistances. The use of a shunt is very necessary with a delicate galvanometer because its sensitiveness is so great that it will only measure directly very feeble currents ; consequently when the deflection to be produced is likely to be beyond the range of the scale only a fixed proportion of the current is allowed to pass through the galvanometer, and the deflection obtained is multiplied by the value of the shunt.

The multiplying value of a shunt is equal to the sum of the resistance of the galvanometer and that of the shunt, divided by the resistance of the shunt, thus $\frac{G + S}{S}$.

For instance, if we have a galvanometer of 9,000 ohms

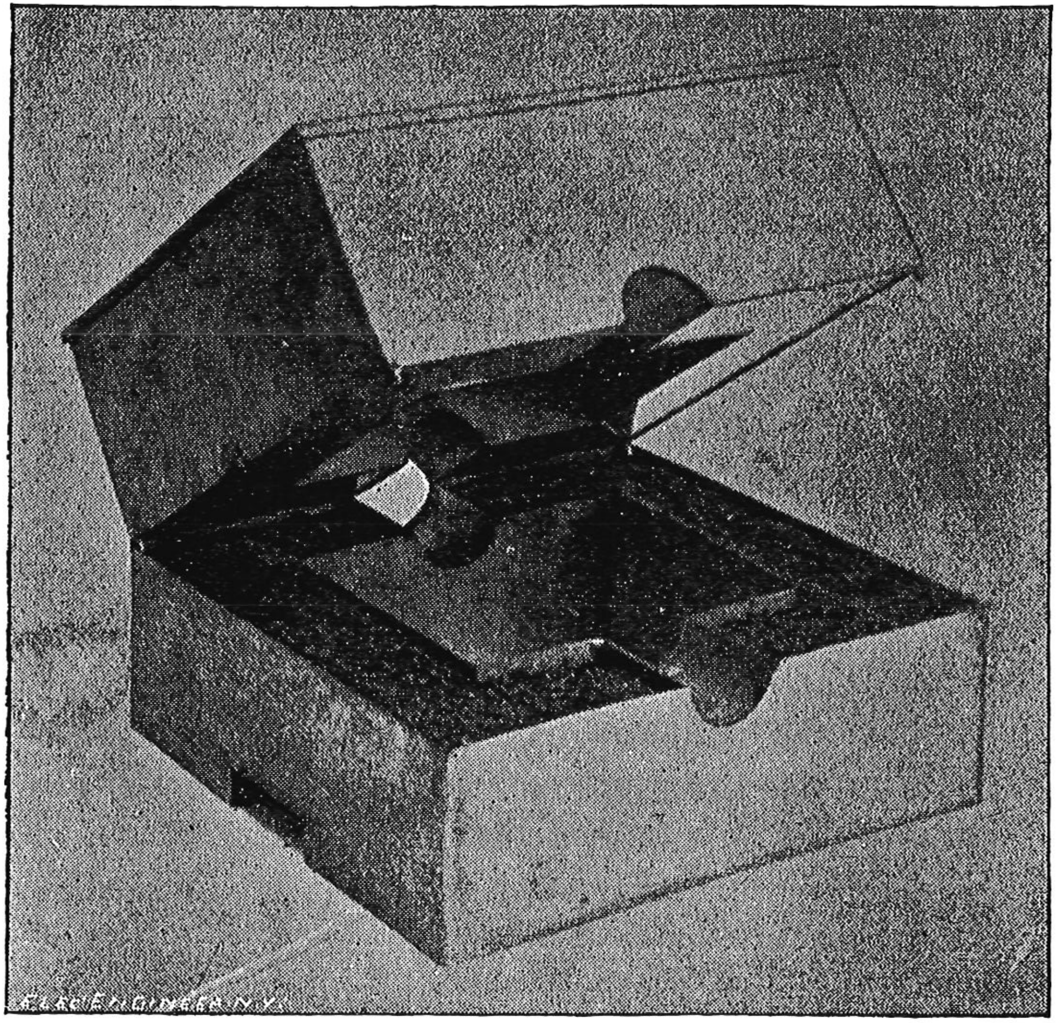

FIG. 11.—MAGNETIC SHIELD.

resistance shunted by a coil of wire having a resistance of 1,000 ohms, substituting these figures for G and S we have, $\frac{9{,}000 + 1{,}000}{1{,}000} = 10$. The multiplying power of the shunt would therefore be 10, and all deflections obtained on the galvanometer with this shunt in circuit would have to be multiplied by ten in comparing them with deflections obtained without any shunt in circuit.

The shunt box generally contains three coils having, respectively, $\frac{1}{9}$th, $\frac{1}{99}$th and $\frac{1}{999}$th the resistance of the galvanometer coils. The deflections obtained with the shunts must be multiplied by 10, 100 and 1,000, according to the coil used. Figs. 12 and 13 illustrate different forms of shunt boxes intended for use with Thomson galvanometers.

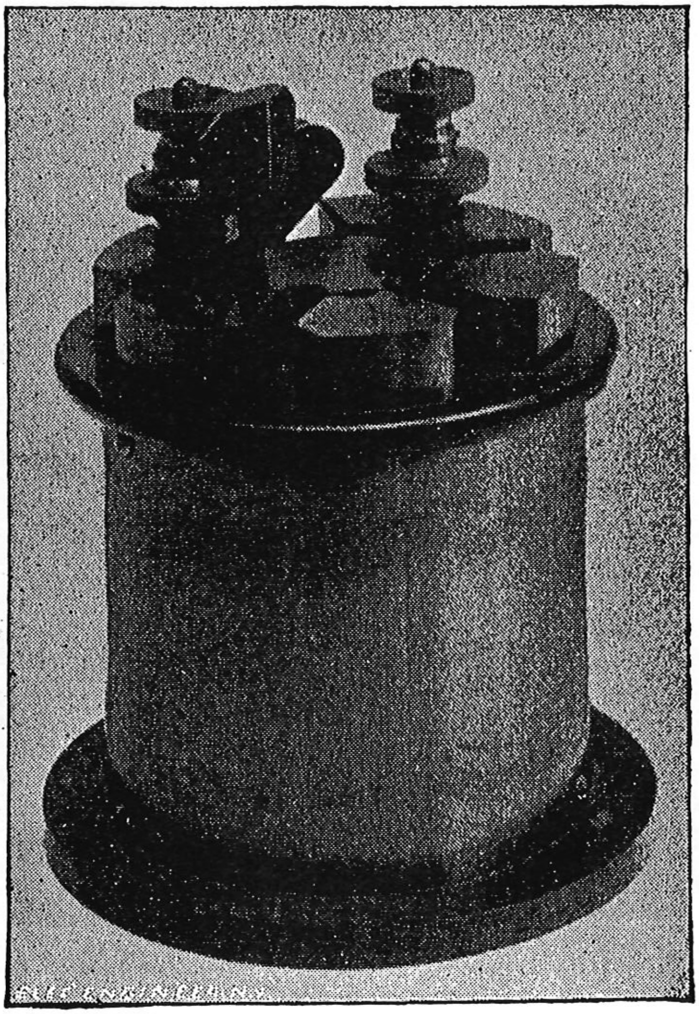

FIG. 12.—SHUNT BOX.

It is sometimes necessary or desirable to make up a shunt of some other multiplying value than ten, one hundred or one thousand, and this is an easy matter if a set of adjustable resistance coils is at hand and the resistance of the galvanometer is known. The resistance of a shunt having a multiplying value n is expressed as follows, $S = \frac{G}{n-1}$. Thus, if our galvanometer has a resistance of 8,000 ohms, and we wish to make a shunt having a

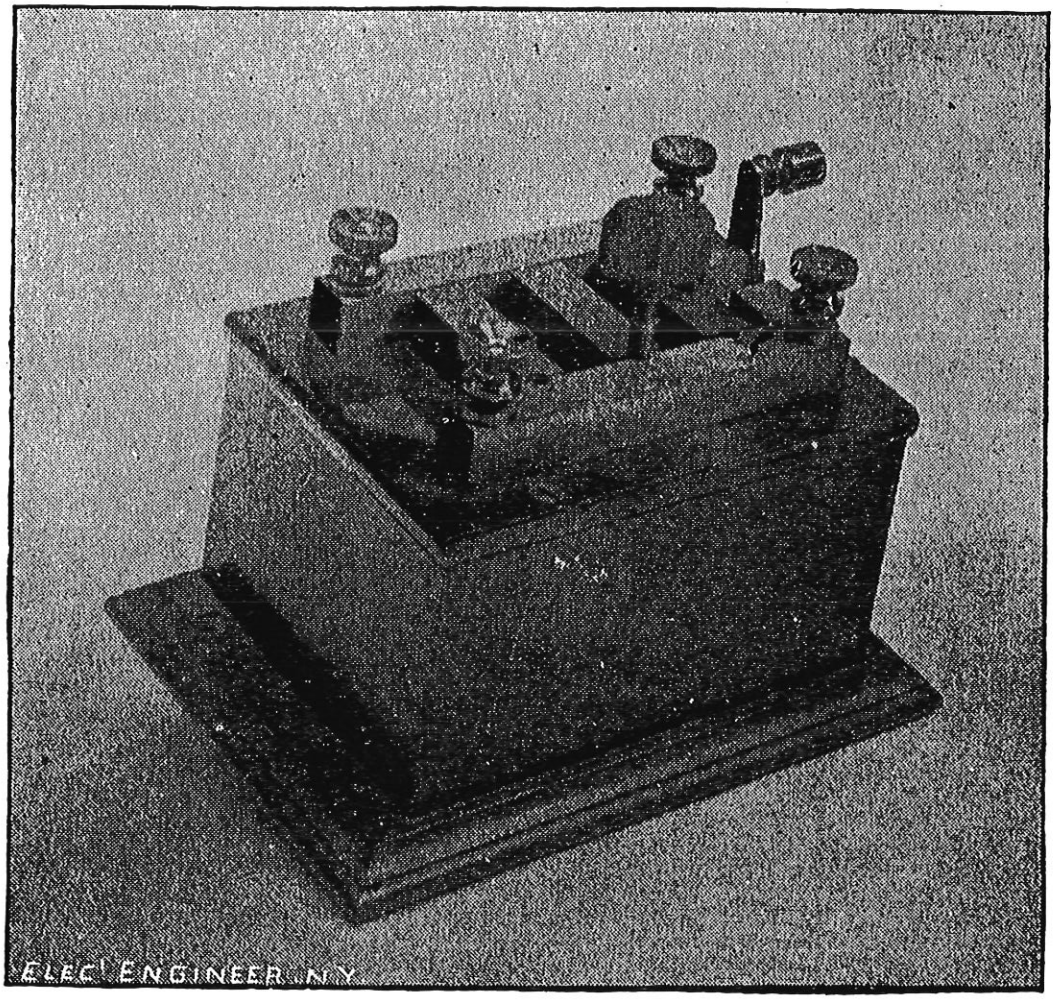

FIG. 13.—SHUNT BOX.

multiplying value of five, the resistance to be given the shunt would be $\frac{8,000}{5-1} = 2,000$ ohms If we find the $\frac{1}{999}$th shunt does not reduce our deflections sufficiently, and we desire to make a shunt having the multiplying value of 5,000 instead of 1,000, then $\frac{8,000}{5,000-1} = 1.6$ ohm, or, to be more accurate, 1.6003 ohm would be the resistance of the shunt required.

The shunt should be placed close to the galvanometer so as to be as nearly as possible subject to the same temperature, and should be connected to it by short thick leads in order not to place any additional resistance between the shunt and the galvanometer.

CHAPTER IV.

Keys.

The keys in general use for cable testing are three in number ; first, the *battery* key ; second, the *discharge* key ; and third, the *short circuit* key.

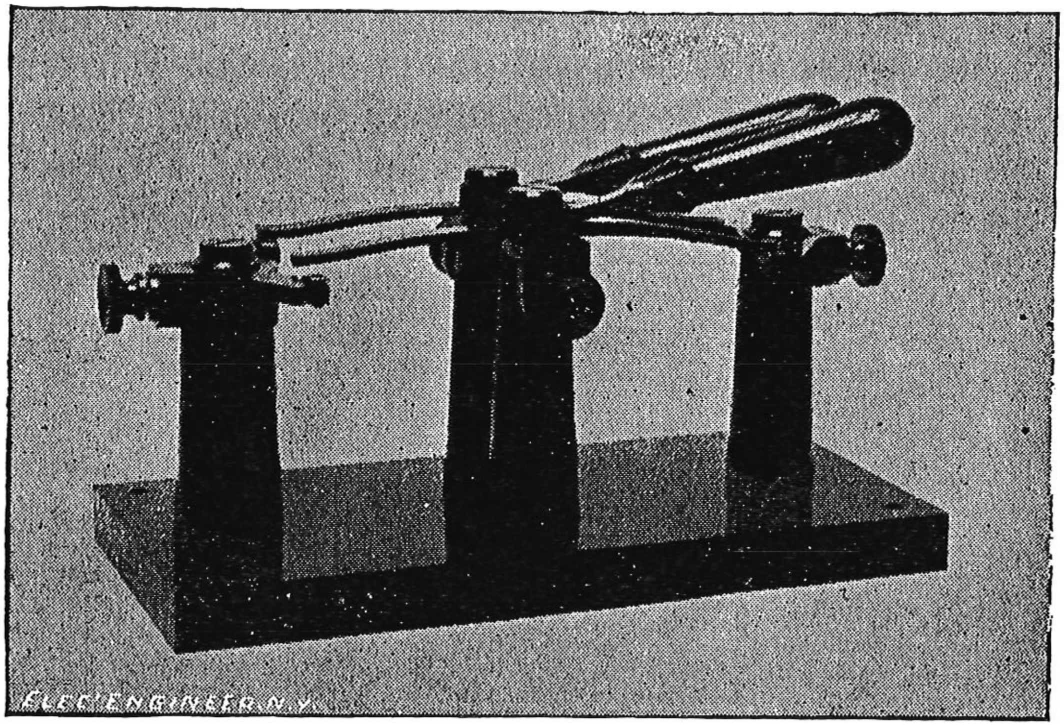

FIG. 14.—RYMER-JONES REVERSING KEY.

The form of battery key illustrated in Fig. 14 is fa superior to that usually employed and shown in Fig. 15. The ordinary reversing key is both clumsy and inconvenient. If the instruments are at all crowded, the cams are difficult to get at without touching the terminals of the key, and if a powerful battery is in use this may result in the reception of a smart shock. Other objections are, that unless the workmanship is of the very best, the cams are apt to bind and work stiffly, and that the construction of the key greatly favors the accumulation of dust. As the contacts depend only upon pressure, the efficiency of the key is soon impaired by the contact points becoming dusty and dirty, while their position renders cleaning a matter of considerable difficulty unless the key is taken apart.

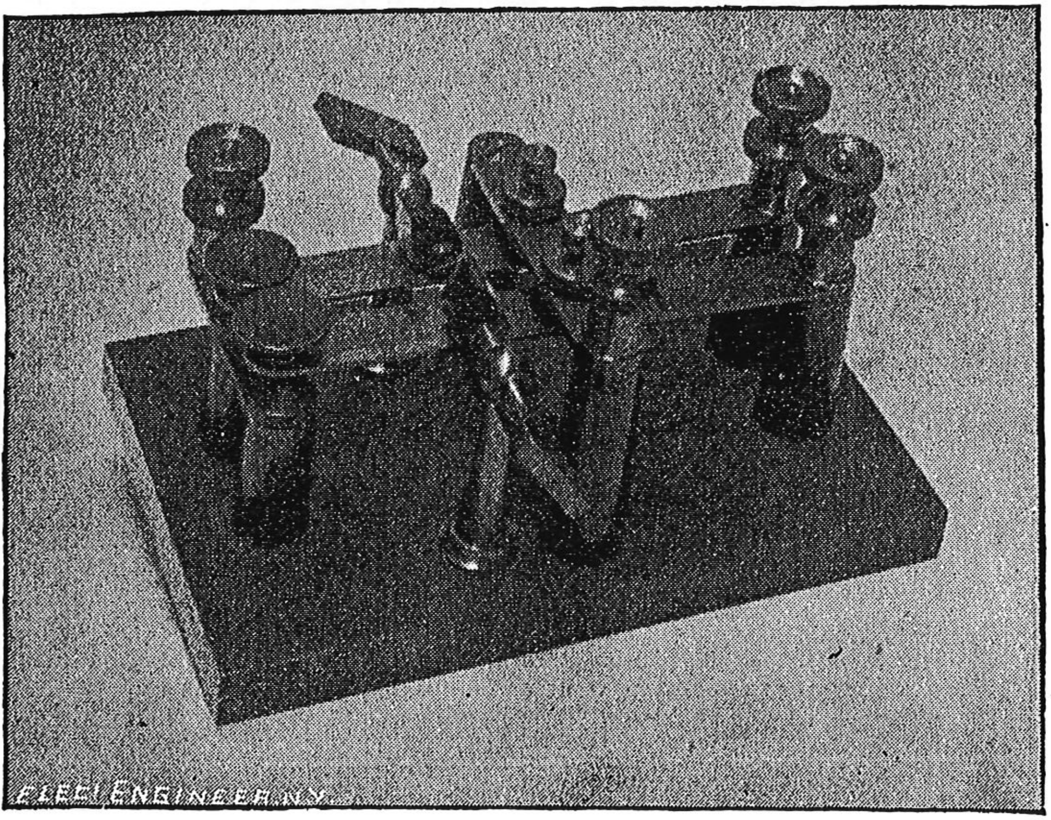

FIG. 15.—BATTERY REVERSING KEY—OLD FORM.

The battery key illustrated in Fig. 14, known as the Rymer-Jones key, consists of two brass levers pivoted on hard rubber pillars and provided with hard rubber handles, by which they can be moved in one direction or the other. These levers make contact at either end with little platinum springs fixed to the ends of crescent-shaped brass plates also mounted on hard rubber pillars. To the under surface of both ends of the levers are fixed platinum contact plates. The hard rubber handle of the left hand lever is provided with a projecting lug of the same material, so that one movement suffices to throw over both the levers. The two poles of the battery are connected to the terminal screws of the crescent-shaped plates, and to the terminal screws on the pivots of the levers are connected line and earth. A simple movement of the hard

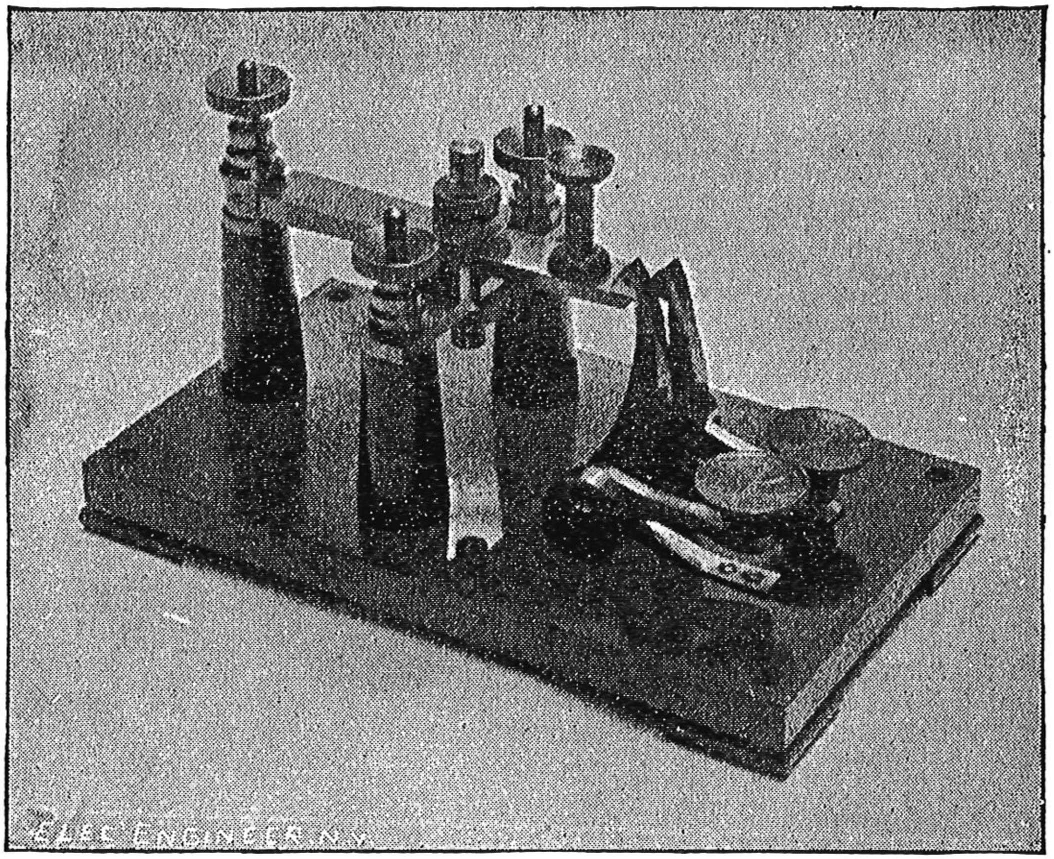

FIG. 16.—THE KEMPE DISCHARGE KEY.

rubber handles puts either pole of the battery to line, and if the handles are separated, so that the levers are free of the front plate and both in contact with the back plate, the battery is insulated and the line is put to earth through part of each lever and the rear plate.

The advantages of this key are its great simplicity—as even with the roughest treatment it would be difficult to get it out of order—and its good insulation and freedom from accumulation of dust. The contacts being made by two rubbing surfaces they are kept clean automatically by the friction from constant use. The handles are well above the terminals and contact plates, so that there is no risk of touching any of the metal parts when manipulating the key.

The *discharge key* is used, as its name implies, for discharging a condenser or cable. It has three connections, one for the condenser or cable, one for the battery, and one for the galvanometer through which the discharge current is allowed to flow in order to obtain a deflection. The necessary parts of the key, therefore, are a hinged lever to which the cable or condenser is connected, a lower contact connected to the battery upon which the lever is pressed to charge, and an upper contact connected to the galvanometer, against which the lever flies when released. A trigger to engage with the end of the lever and hold it down against the lower contact for charging, or midway between the two contacts when it is desirable to insulate the charged cable or condenser, completes the key.

These necessary parts have been made up in various different patterns, among which the best and most useful are the Kempe discharge key, Fig. 16, and the Webb key,

Fig. 17. In the former, a stout lever of brass, hinged at one end, plays between an upper and a lower contact; the free end of the lever, when pressed on the lower contact, is held by two triggers pivoted in front of the lever and actuated by ebonite knobs. One of these knobs is marked "Discharge" and the other "Insulate." If the knob marked "Insulate" is depressed, the lever is released from the lower contact, but is caught by one of the triggers before it reaches the upper contact; the knob marked "Discharge," when pressed, allows the lever to fly all the way up, whether it is in the insulated position or pressed down against the lower contact. This arrangement is effected by means of an engagement between the two triggers which causes both to be withdrawn when the "Discharge" knob is pressed, while only one is withdrawn when that marked "Insulate" is pressed. The pivot of the lever and the two contact plates are mounted on hard rubber pillars.

The Webb key is of simpler construction but not quite so automatic in its movements, although the insulation is better and there is no risk of confusion, there being only one trigger. It consists of a long brass lever pivoted at one end and pressed upward against a contact by a stiff spring. Immediately in front of the free end of the lever is a hard rubber trigger, pivoted to the base of the key, carrying a projecting strip of brass, which holds the lever down when it is pressed against the lower contact. The end of the lever has a step cut in it, so that if the trigger is pulled outward slightly, the lever is released from the lower contact, but is held before reaching the upper contact by the projecting brass strip catching the step; the lever is then insulated. On pulling the trigger out a little further the lever is wholly released and brings up against the upper contact, effecting the discharge. Of course, if the trigger is pulled out sharply at first, the lever flies at once from the lower contact to the upper, making the discharge instantaneously.

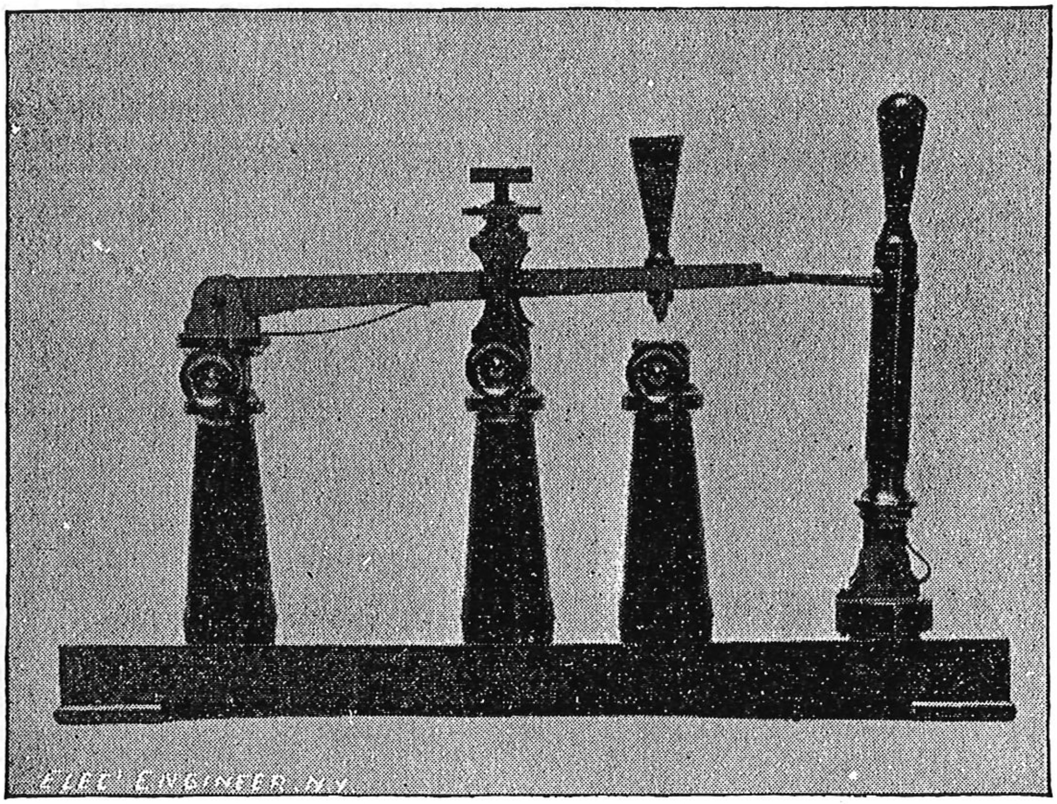
ELEC'L ENGINEER. N.Y.

FIG. 17.—THE WEBB DISCHARGE KEY.

The reason for these attachments for insulating the lever is to enable a discharge taken after the cable has been charged, and then insulated for a certain time, to be compared with the instantaneous discharge. For instance, if a cable is charged for fifteen seconds and then discharged instantaneously, a certain deflection will be obtained; but if it be charged for fifteen seconds, then insulated for one minute, and then discharged, the deflection will be less than that obtained with the instantaneous discharge, because a slight discharge has been taking place during the minute through the dielectric to earth. In the case of a good submarine cable submerged in deep water, this difference will be very slight—about three per cent.—but in a cable having a low insulation there would be a much greater difference.

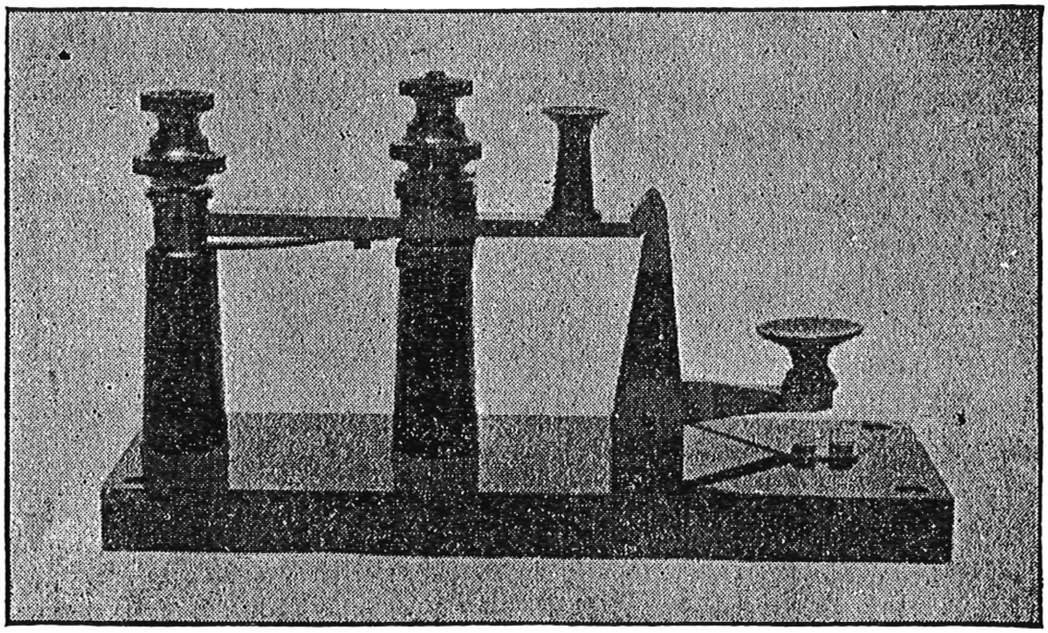

FIG. 18.—SHORT CIRCUIT KEY.

A form of *short circuit* key is shown in Fig. 18. As its name implies, the function of this key is to short circuit the galvanometer ; being bridged across the galvanometer circuit, when the key is closed, a direct path for the current is provided by the lever of the key and no current passes through the galvanometer; when the key is opened the galvanometer is thrown in circuit and the current passes through it. By the use of this key the galvanometer is protected from being violently deflected by the first rush of charge when current is turned on, and when a balance is being obtained in a resistance test with the dial bridge.

The form of key shown consists of a brass lever, hinged at one end, and playing in a brass bridge, having a metallic contact above and a stop of insulating material below. On the hard rubber pillar which supports the lever, and on the bridge, are placed double binding-posts to which the wires are attached. In its normal position the lever is pressed by a stiff spring against the upper contact, and forms a direct connection between the binding posts ; by pressing it down the contact is broken, thereby removing

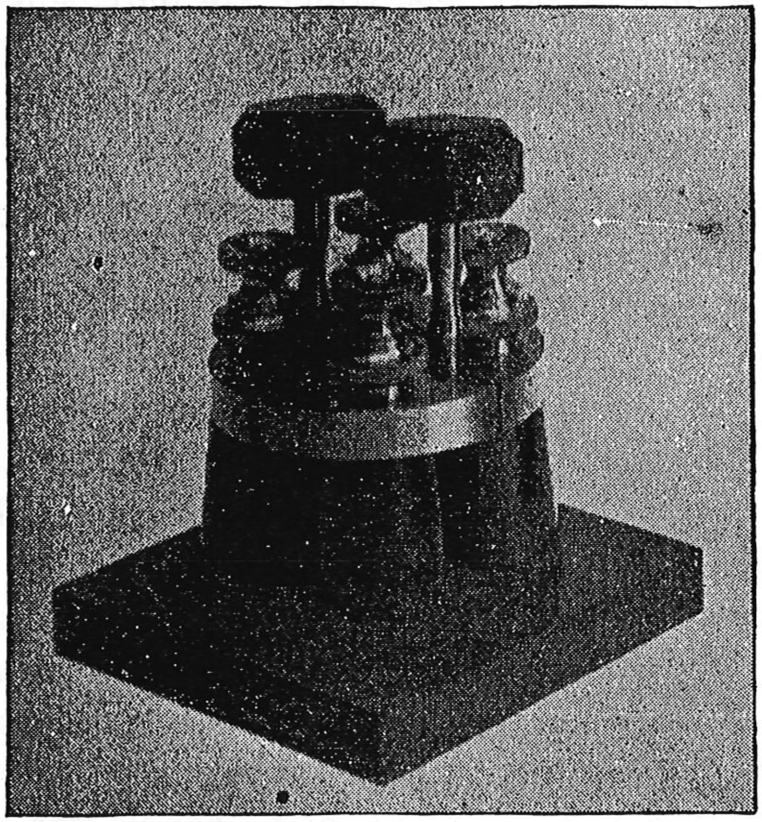

FIG. 19.—DOUBLE PLUG REVERSER.

the short circuit. A trigger attachment, mounted opposite the end of the lever, holds the key in the open position as long as may be desired.

A better form of this key than the one shown, is that in which, instead of the pivoted lever, a strip of springy brass is used, being held rigidly at the end fixed to the hard rubber pillar. With this kind of key there is no risk of imperfect contact through weakening of the spring, a very annoying defect to which the other is liable.

Besides these keys, which are indispensable, a very useful instrument on the testing table is a galvanometer reverser. It is often convenient to have all the deflections on the same side of the scale, and to effect this, when the battery is reversed, it is necessary to change the direction in which the current enters the galvanometer. To do this, any form of battery reversing key, such as those shown in Figs. 14 and 15, may be employed, but preference should be given to the double-plug switch shown in Fig. 19.

This consists of a circular plate of brass, divided into four quadrants, which are mounted on hard rubber pillars, rising from a base of the same material. Each quadrant is provided with a double binding-post for attaching wires, and two brass plugs, with insulating handles, serve for connecting the quadrants in pairs. This switch is connected in the galvanometer circuit, and the direction in which the current enters the galvanometer may be changed by simply altering the plugs. The plugs should have long stems, so that the hard rubber handles or tips may project clear above the binding-posts, giving greater convenience in handling than the short plugs used for resistance boxes and bridges.

CHAPTER V.

Resistance Boxes.

In a complete outfit of testing instruments a high resistance for taking the constant of the galvanometer and a Wheatstone bridge for measuring resistances are absolutely necessary, and a box containing a number of coils having different resistances is a very useful addition.

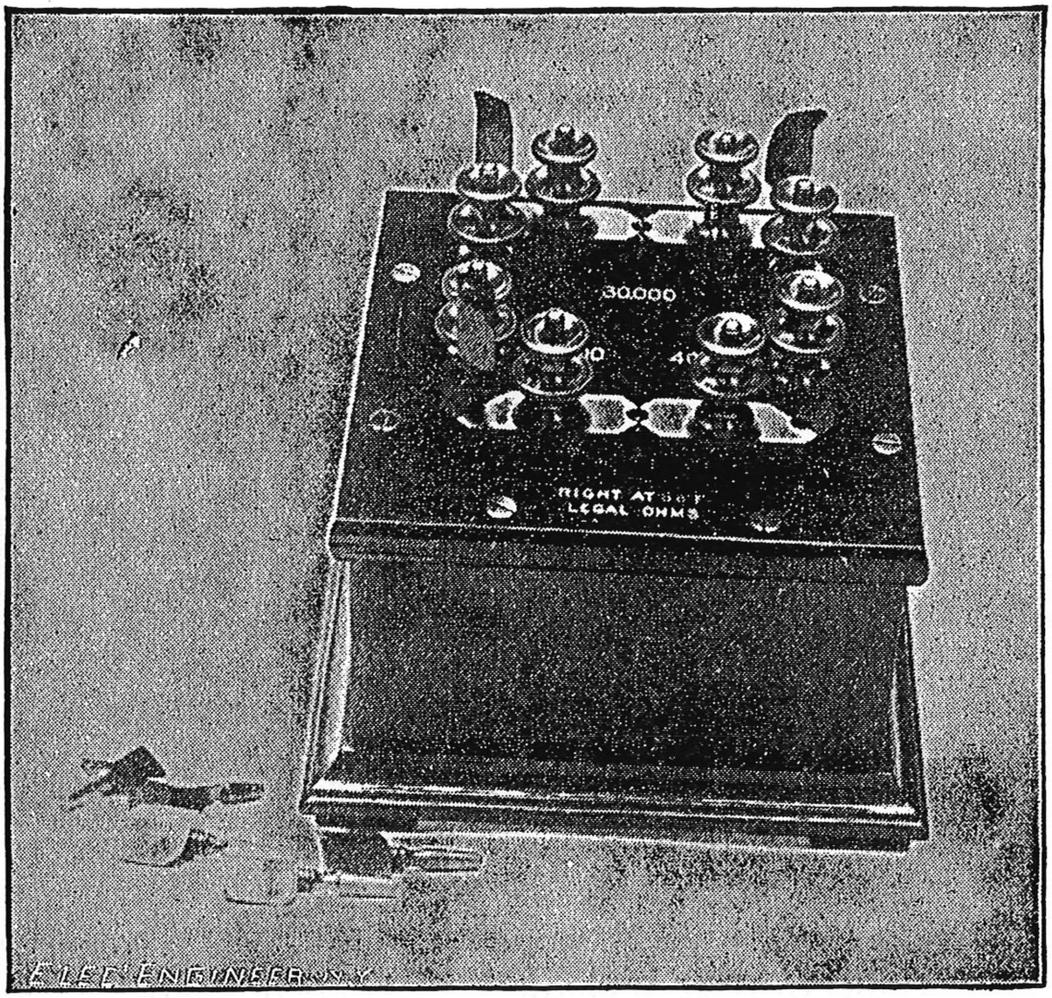
30,000
10
40
RIGHT AT
LEGAL OHMS
ELEC. ENGINEER N.Y.

FIG. 20.—HIGH RESISTANCE BOX.

The high resistance box generally contains four coils, of 10,000, 20,000, 30,000 and 40,000 ohms resistance, making 100,000 ohms resistance in all. This instrument is illustrated in Fig. 20. The ends of the coils are brought to brass blocks on the top of the box, these blocks being provided with double binding posts and connecting plugs, so that the coils may be connected in any combination desired, although the most general manner of using the coils is all in series, giving the full resistance of 100,000 ohms.

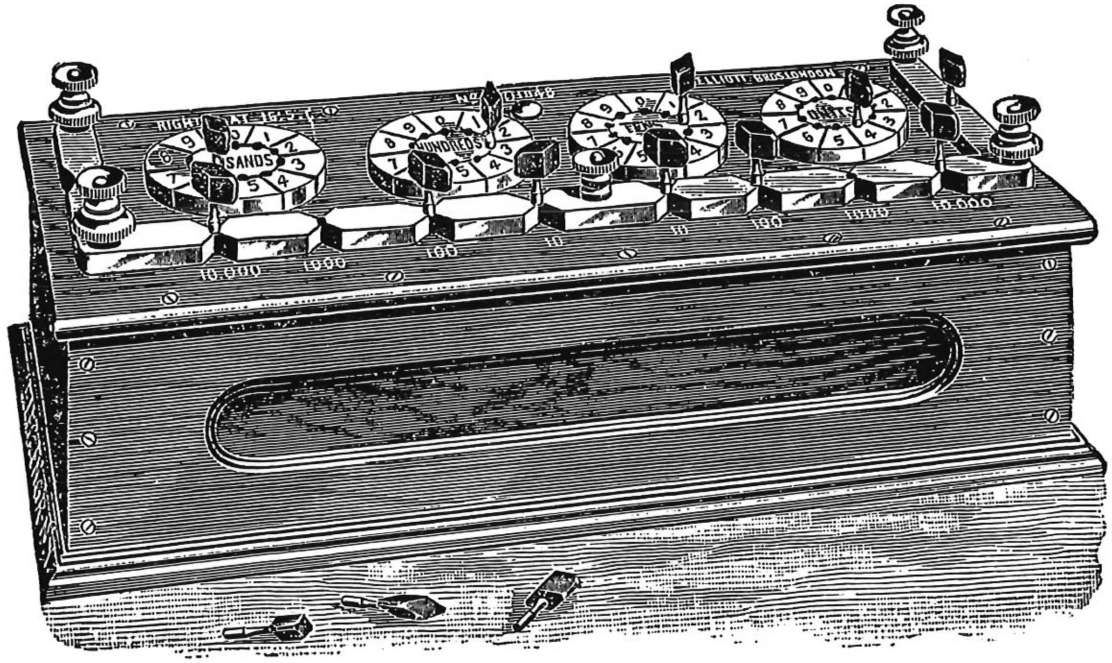

FIG. 21.—WHEATSTONE "DIAL" BRIDGE.

High resistances are also made up containing ten coils of 100,000 ohms each, giving a total of one megohm. A megohm resistance enables the galvanometer constant to be taken with greater accuracy and allows of the galvanometer being adjusted to its maximum sensitiveness ; but such a high resistance is very expensive, costing about seven times as much as a 100,000 ohm box. A firm of electrical instrument makers in England have lately brought out a high resistance box, containing a mixture of glass and metal, instead of wire; these instruments have to be calibrated after they are made, as it is impossible to give the mixture any fixed resistance. They generally have a resistance of several megohms, but rarely come out in round numbers, running, instead, to at least two decimal places. This is somewhat inconvenient in multiplying, but as an offset the instruments are very cheap, the price being about one-half that of a 100,000 ohm box. Given this advantage, and if the resistance remains reasonably constant with time and temperature, this form of high resistance box will no doubt find many users. I understand that it has already been adopted by several of the submarine cable companies.

The *Wheatstone bridge* is made up in a variety of forms, of which the most convenient are those known as the dial and the Post-office patterns. Both these styles have their advantages, the former being very easy to read and involving the handling of few plugs, while the latter is more compact and complete in itself, as the battery and galvanometer keys are permanently connected to the coils and form part of the instrument. Dial bridges are now being manufactured, however, with this convenience, the keys being placed in front of the dials similarly to the arrangement of the Post-office bridge.

The function of the Wheatstone bridge in the measurement of resistances has already been explained and will be further treated of when we come to actual testing instructions, so that it will be sufficient here to describe the connections and plan of the instruments themselves. The dial form is illustrated in Fig. 21. The coils are arranged in sets of thousands, hundreds, tens and units ; sometimes a fifth set of tenths of an ohm being added. The ends of the coils are brought to the brass segment blocks arranged around a circular plate of brass.

Starting from one end of the proportional coils, connection is made to the zero segment of the end set of blocks ; the resistance coils are placed between the segment blocks, one between 0 and 1, one betweeen 1 and 2, and so on, and the circular plate of each dial is connected to the zero segment block of the next, and so on throughout. Thus the number of the segment block connected by the plug to the circular plate represents the number of resistance coils in circuit, whether they be units, tens, hundreds, or thousands. The proportional coils terminate in brass blocks placed at one side of the adjustable resistance coils. These proportional coils form the two arms of the bridge or balance, and by altering their relation to each other the adjustable coils may be adapted to measure either very high, or very low, resistances. In the dial bridge the two sets of proportional coils usually consist of 10, 100, 1,000 and 10,000 ohms resistance. The battery current splits at the centre of the proportional coils, one part going through one set to the adjustable resistance coils, the other part going through the opposite set to the unknown resistance to be measured.

If the resistance unplugged in the proportional coils is the same on both sides, the readings obtained by the adjustable coils will be the actual value of the resistance which is being measured. If the resistance to be measured is very small we can obtain its resistance to three decimal places by unplugging the 10,000 ohm coil in the arm nearest the adjustable coils and the 10 ohm coil in the arm to which the unknown resistance is connected. Then, as b (the resistance between battery and coils) is 1,000 times greater than a (the resistance between battery and unknown resistance), so d (the resistance in coils) is 1,000 times greater than x (the unknown resistance), and the reading obtained must be divided by 1,000 to find the true value of x.

In the same way, if the resistance of x is known to be much greater than the maximum value we can give to d while a and b are equal, then, by making a greater than b, the reverse is the case, and the readings must be multiplied by the ratio of a to b in order to find the value of x. With proportional coils of 10, 100, 1,000 and 10,000 ohms, therefore, the bridge has a very wide range, being capable of measuring from .001 of an ohm to 10 megohms. It must be borne in mind that some resistance must always be unplugged in the proportional coils, as otherwise the galvanometer, which is connected to their extremes, would be short-circuited.

CHAPTER VI.

Wheatstone Bridges.

The Post-office form of bridge, illustrated in Fig. 22, is smaller and more compact than the dial pattern and is therefore more suitable for out-door and portable work than for laboratory use. Its range is more limited, as the proportional coils only contain three different resistances, 10, 100 and 1,000 ohms, instead of four; it can, therefore, only measure from .01 of an ohm to 1 megohm.

The adjustable coils are sixteen in number, their values being 4, 3, 2, and 1 in thousands, hundreds, tens and units, giving any combination up to 9,999 ohms. The coils are thrown in circuit by taking out plugs instead of putting them in, as in the dial bridge, and the resistance measured is ascertained by adding up the values of the various coils unplugged, which is not quite such a simple operation as reading off a figure from each of four dials. The two small keys fixed in front of the coils serve, the one on the right, for putting on the battery, and that on the left, for throwing the galvanometer in circuit. The right hand key is generally held down and the left tapped from time to time as the plugs are manipulated; in this way sudden throws of the galvanometer are avoided, the left hand key not being kept down for any length of time until an even balance is nearly obtained. A small clamp for holding the battery key down permanently would be a useful addition to a Post-office bridge, as the two hands of the observer would then be free for manipulating the plugs and the galvanometer key.

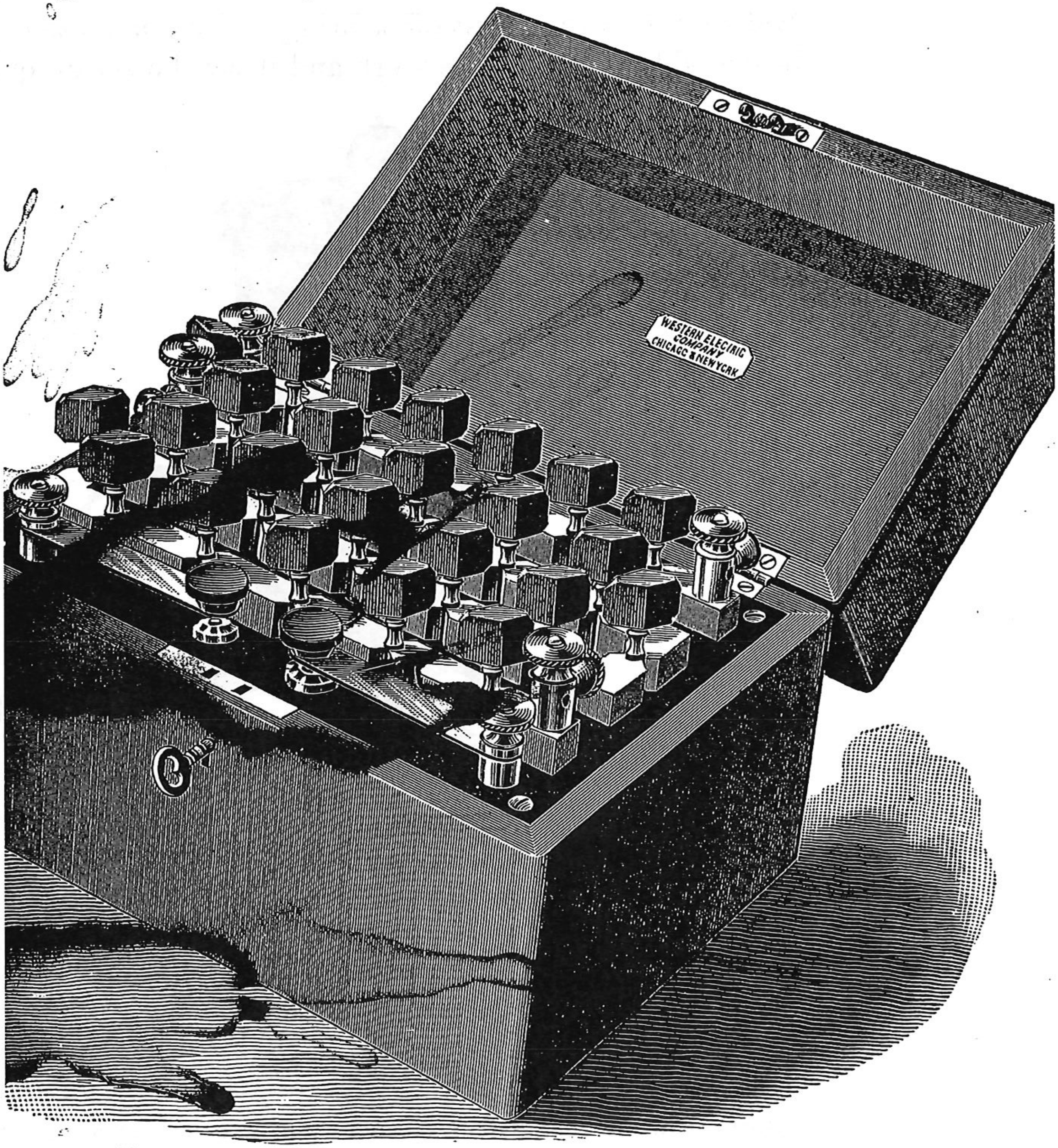
WESTERN ELECTRIC COMPANY CHICAGO & NEW YORK

FIG. 22.—WHEATSTONE BRIDGE, POST OFFICE FORM.

The small astatic detector galvanometer, illustrated in Fig. 23, is an excellent little instrument for work-shop or factory use with a Post-office bridge. Its small size renders it available for portable work and it can be set up quickly and in places where a reflecting galvanometer would be out of the question, while it is sufficiently sensitive for ordinary resistance measurements.

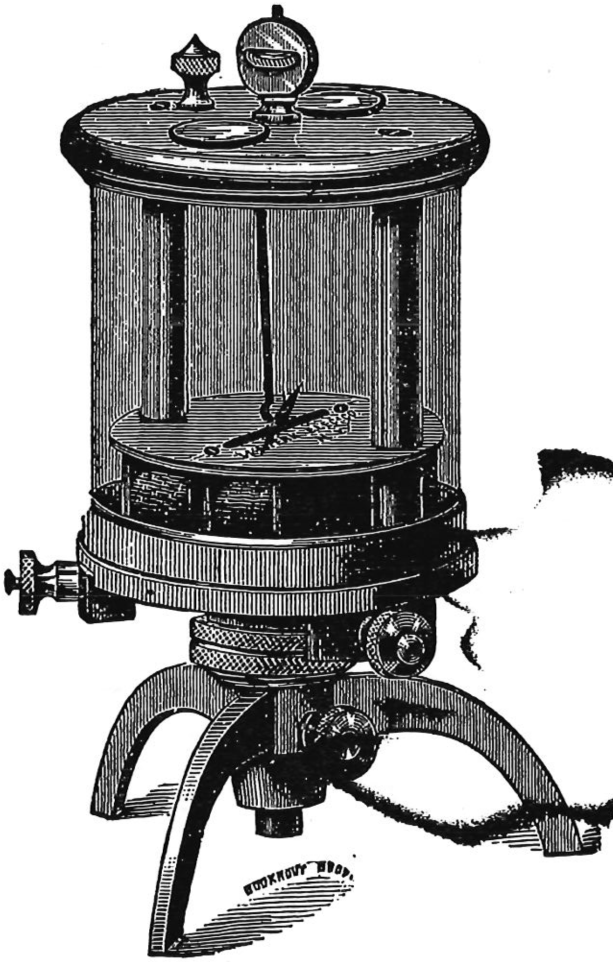
BOOKHOUT SROS.

FIG. 23.—SMALL ASTATIC GALVANOMETER.

A box containing adjustable resistance coils from 1 to 1,000 ohms is a useful adjunct to a set of testing instruments. As an instance of its usefulness, reference is only needed to the labor of working out the multiplying value of shunts of different resistances, whenever a shunt is required of a different value to any of the three unadjustable coils supplied with the galvanometer. Of course the resistance of a galvanometer varies considerably with the temperature, and a table of shunt resistances and multiplying values would be incorrect except at the temperature at which the resistance of the galvanometer was exactly that used in calculating the table. By connecting an adjustable resistance in circuit with the galvanometer the variation in resistance due to temperature may be made up and the resistance of the galvanometer kept always practically the same. In this way a table of shunts can be made out, giving the multiplying value for various resistances, using the formula given before, $\frac{G + S}{S}$. This arrangement, facilitating the use of shunts of various values, will be found very useful in factories where numbers of cables and wires have to be tested daily; the chief advantage being that the galvanometer can be shunted so as to give any desired deflection, large deflections, of course, being read with greater ease and accuracy than very small ones.

CHAPTER VII.

Condensers.

The simplest method of measuring the electrostatic capacity of a wire or cable, is, as has already been stated, by comparing the charge or discharge with the charge or discharge of a standard condenser. A condenser is simply a Leyden jar arranged so as to occupy the smallest possible space; the condensers used in telegraphy and telephony consist of leaves of tin foil separated by leaves of paraffined paper. In making condensers for standards for testing purposes a finer degree of adjustment is necessary, and plates of mica are generally used for the insulating medium, instead of paraffined paper.

In the Leyden jar one surface of tin foil is connected to ground and the other to the source of electricity by means of which it is charged, the glass bottle serving as the separating medium or dielectric. In order to obtain a large charging surface the alternate plates of tin foil in a condenser are connected together, thus forming two large plates made up of a number of small ones, much as a number of cells of battery connected in parallel practically form one cell having very large plates. Each set of plates is connected to a brass block on the top of the case; when the condenser is in use one of these blocks is connected to earth and the other to the charging key.

The unit of capacity is the "farad." A condenser which would hold a charge of one coulomb at a difference of potential between the plates of one volt would have a capacity of one farad. Such a condenser would be of enormous size, and the farad is such an inconveniently large unit that it has been necessary to divide it by one million to arrive at a unit of reasonable proportions ; consequently measurements of capacity are always expressed in microfarads or fractions thereof. Standard condensers were first made for submarine cable testing, and as the capacity of a submarine cable is about one-third of a microfarad per mile the standards were always made of that capacity for convenience in comparison.

For general work, however, a non-adjustable condenser is not at all a convenient instrument to deal with, as it is highly necessary to be able to vary the capacity of the condenser, using one-tenth, or one-fifth, or some other fraction of a microfarad, instead of always one-third. Until lately adjustable condensers have had one serious defect, namely, that the different sections could only be connected in parallel, instead of being arranged so as to be connected both in parallel and in series. Standard condensers are now made, however, so arranged that the various sections may be connected either in multiple or in series, or the sections may be used as separate condensers if desired.

To appreciate the advantage of having a condenser arranged in this manner it is necessary to discuss briefly the laws governing the joint capacity of condensers connected in parallel and in series. These laws run on parallel lines to those referring to the joint resistance of divided circuits, but with condensers exactly opposite results are obtained, as by connecting them in parallel the capacity is increased, and by connecting them in series the capacity is diminished; with resistances the effect is reversed. Connecting in series increases the resistance and connecting in parallel or in "multiple arc" diminishes it.

If we have a number of condensers joined in parallel the joint capacity will be equal to the sum of their respective capacities. When we connect them in series a very different result is obtained; their joint capacity is then only a fraction of the capacity of a single condenser. When condensers are joined in series their joint capacity is determined by the same law that governs the joint resistance of parallel circuits. The joint resistance of two wires joined in parallel circuit is equal to their product divided by their sum, thus: $\frac{R_1 R_2}{R_1 + R_2}$ ohms,

and the joint capacity of two condensers joined in series is expressed in the same manner:

$$\frac{F_1 F_2}{F_1 + F_2} \text{ microfarads.}$$

If we have three condensers in series the joint capacity is

$$\frac{F_1 F_2 F_3}{F_1 F_2 + F_1 F_3 + F_2 F_3}.$$

The joint capacity of any number of condensers connected in series may be arrived at in the same manner, or in simpler form it may be written thus:

$$\frac{1}{\frac{1}{F_1} + \frac{1}{F_2} + \frac{1}{F_3} + \frac{1}{F_4}, \text{ etc.}}.$$

Putting this expression into words, it is evident that the joint capacity of a number of condensers joined in series is equal to the reciprocal of the sum of the reciprocals of their respective capacities.

Thus if we have a condenser having ten sections of a capacity of one-tenth of a microfarad each, the joint capacity of the ten sections connected in parallel will be one microfarad, and if one side of each section is permanently connected to the earth block the range of the condenser will be confined between one-tenth and one microfarad. If, however, the plates of each section are connected to insulated blocks so that the sections may be disconnected from the earth block and connected together in series, then the range of the condenser will be greatly increased as far as small fractions of a microfarad are concerned. If we connect the whole ten sections in series, the rule of "the reciprocal of the sum of the reciprocals" shows that the joint capacity will be .01 microfarad; therefore a condenser arranged in this manner has a range of capacities from .01 to 1 microfarad.

In comparing small capacities, such as those of overhead lines or short lengths of underground cable, it is a great convenience to be able to adjust the standard condenser to give about the same deflection as the wire or cable to be measured, and the accuracy of the test is also greater than if widely different deflections are obtained. The convenience, therefore, of employing an adjustable condenser, the sections of which can be connected either in parallel or in series, is obvious.

Fig. 24 illustrates a condenser having a total capacity of 4 microfarads and a range of capacities from .00985 microfarad up to the limit. This condenser has twelve sections; one of 2 microfarads, one of 1 microfarad, and ten of one-tenth each. The alternate plates of each section are connected to small brass blocks, insulated from the long strips running the full length of the condenser; the plugs are provided with small binding screws, and for connecting the sections in series they are inserted in the holes in the blocks and connected diagonally with short pieces of wire, the two end blocks of the series being plugged to the long strips so as to make connection with the discharge key and earth.

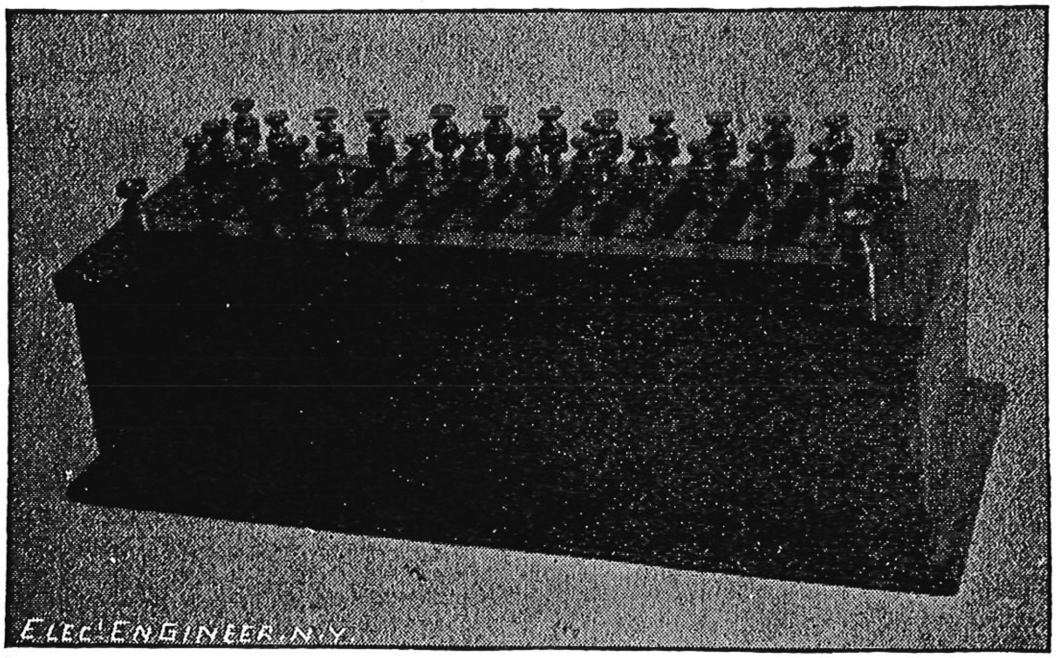

FIG. 24.—CONDENSER FOR TESTING.

In Fig. 25 an improved form of the multiple series adjustable condenser is shown. The blocks are arranged so as to overlap each other, and the different sections can be joined in series by means of the plugs alone without the use of connecting wires. The plugs are fitted with binding screws so that the different sections can be used as separate condensers if desired, each section being rendered independent of the others by connecting wires to the plugs and inserting them in the blocks. This instrument is the *ne plus ultra* of adjustable standard condensers; the style illustrated is divided into five sections of one-tenth each, and has a range of capacities from .02 microfarad to .5 microfarad.

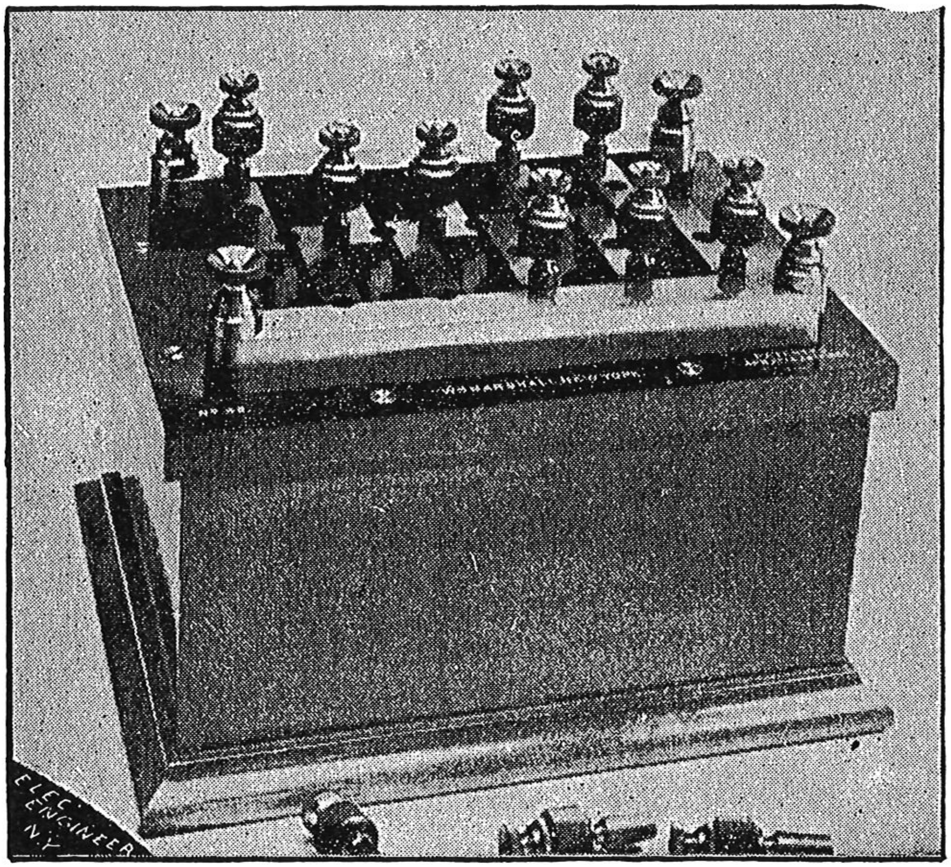

FIG. 25.—IMPROVED MULTIPLE SERIES ADJUSTABLE CONDENSER.

When not in use, standard condensers should always be short-circuited by inserting the plugs between the brass blocks to which the plates are connected; in this manner any residual charge is neutralized.

CHAPTER VIII.

Testing Batteries and Accessories.

The battery is a very important item in the testing outfit. For a test on an insulated wire to mean anything, it must be made with a high E. M. F., and not less than 100 volts should always be employed, at any rate for testing wires insulated with rubber, gutta-percha or any of the rubber compounds. The testing battery must be constant, and should have a fairly low internal resistance, and a type of cell should be used which requires the least attention, because as one or two hundred cells must be employed, the labor of maintenance and inspection is of course very considerable. In cable factories it is customary to use a battery of from 200 to 500 cells for insulation tests.

A set of accumulators form an ideal battery for testing, but a large number of secondary cells is seldom available. The next best is some form of Daniell, either the original Daniell or the Minotto, but not the ordinary gravity batteries, as the solutions in these cells diffuse quickly unless the battery is doing constant work. In many cases Leclanché cells are used for testing batteries and answer very well, as they require very little attention.

The battery most frequently used for testing work in this country is the chloride of silver cell, made up in sets of 50 or 100. This battery has great advantages over all others in point of compactness and portability, and the ease with which any number of cells may be connected.

The chloride of silver cells require very careful handling to keep them in good order, as, if the battery is worked on a low resistance, or short-circuited, several damaged cells will probably be the result. As portable testing sets do not always receive the most careful handling, these batteries frequently need the attention of the manufacturers to keep them up to the mark. The cells have a pretty high internal resistance to start with, and this increases with time, mounting up sometimes to an alarming figure.

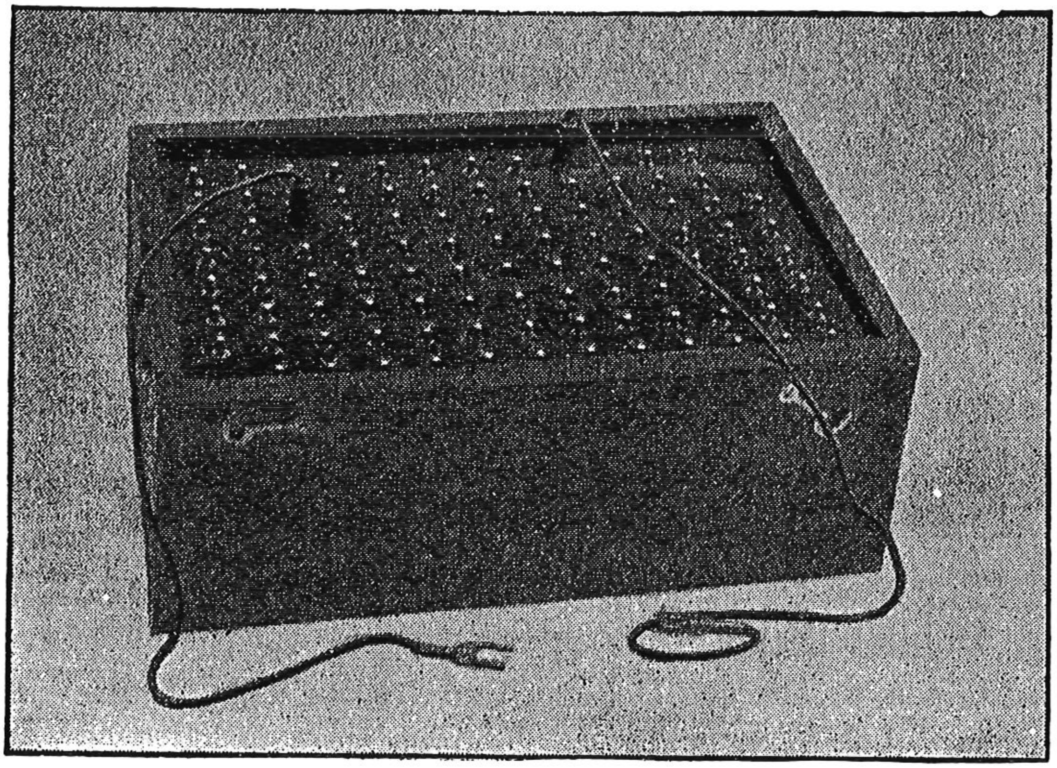

FIG. 26.—CHLORIDE OF SILVER BATTERY—100 CELLS.

The small commutator usually provided with the portable testing batteries should never be used. It is a most unsatisfactory and vexatious instrument, always working loose and making bad contact; or, if screwed up tight, metal dust is ground off the points and distributed over the plate so as to partially short-circuit the battery. It is somewhat surprising that the manufacturers of the batteries should still cling to this very inefficient style of reverser.

In Fig. 26 is illustrated a 100 cell chloride of silver battery. The fixed commutator is discarded and the connecting cords are provided with forked tips by means of which they can be connected to a battery reversing key of proper design (such as that shown in Fig. 14). The cover of the case is made entirely removable instead of being hinged. this arrangement being more convenient for work in a permanently fitted up testing room.

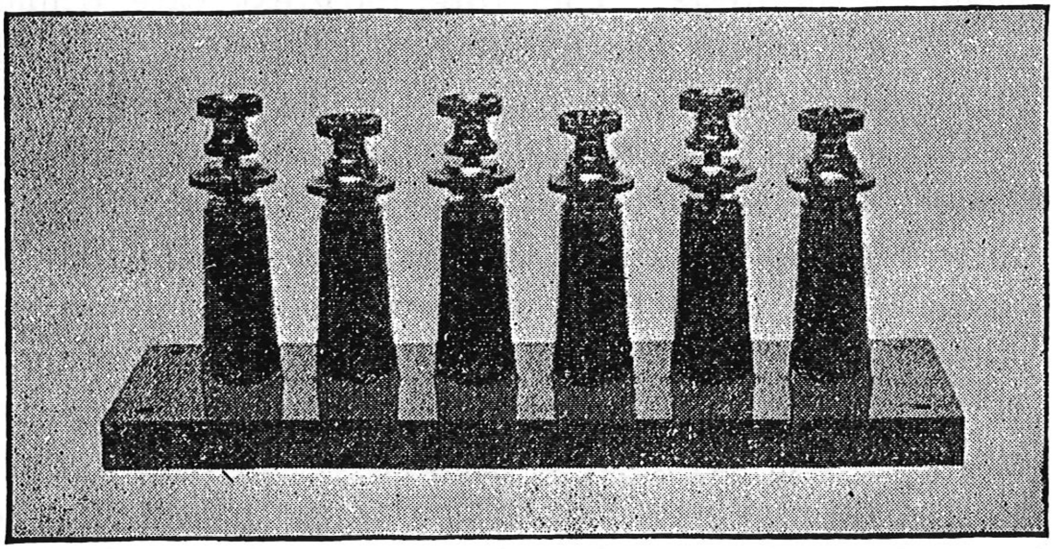

FIG. 27.—INSULATED DOUBLE BINDING POSTS.

The testing battery should be placed in a well protected situation so that it may be kept free from dust and dirt, and above all the entire battery should be thoroughly well insulated, as a badly insulated battery will disorganize the work and render the tests valueless. If Daniell or

Leclanché cells are used they should be placed on wooden stands raised from the floor or shelving by means of hard rubber feet about four inches long; the cells should be well separated from each other and the glass jars should be kept dry and clean; they should be inspected frequently and any incipient signs of "creeping" should be attended to at once. It is of great importance in testing that the battery shall be perfectly constant; any slight defect in the battery will affect its constancy and neutralize the value of the tests. Therefore, too great care cannot be taken in avoiding the appearance of any such trouble, or in remedying it after the slightest indication of its existence.

In a testing battery the cells are of course always connected all in series, as for insulation tests the full E. M. F. is generally required. In measuring conductor resistance and electrostatic capacity it is only necessary to use from five to ten cells. With the chloride of silver battery it is a very easy matter to connect any desired number of cells to the battery reverser, as one pole of each cell terminates in a small nipple on which the plugs of the connecting cords fit tightly, and in order to vary the number of cells the only operation necessary is to alter the position of one of the plugs. With a battery composed of 100 Leclanché cells permanently connected in series, the question of changing the battery power quickly is not so simple, involving the connection of wires, which is rendered additionally troublesome when the battery, as is generally the case, is placed in a more or less inaccessible position.

The best plan of getting round this difficulty is to provide a number of insulated binding posts on the testing table to which wires from the battery may be permanently connected; it is then an easy matter to join up the battery key with the number of cells required for any particular test.

Let us assume that we have a battery of 100 cells. To the testing table, or to the wall at the side, or in any position that may be most convenient and accessible, is screwed a set of double binding posts mounted on hard rubber pillars and base. To the binding post number one a wire is run from the zinc pole of the battery and the copper pole is connected to post number six; to the intermediate posts wires should be run from the copper poles of the first, fifth, tenth and twentieth cells. One terminal of the battery reversing key being connected to the zinc binding post, it is an easy matter to connect the other terminal of the key so as to obtain battery power of one, five, ten, twenty, or the full number of cells, by simply changing one wire. These combinations of cells are all that will be required for general testing, and the connections from the battery to the pillar binding posts once made, the battery need never be touched except for inspection or removal of defective cells.

A set of insulated double binding posts suitable for making the battery connections described above is shown in Fig. 27.

The testing room is generally some distance from the terminals of the cables to be tested, or, in a factory, from the tanks in which the wires and cables are submerged.

This separation, however inconvenient, is necessary in order to secure quietness and freedom from magnetic and mechanical disturbances likely to affect the steadiness of the galvanometer.

In order to make connection with the cables to be tested, a number of permanent leads, which should be of the best possible description, heavily insulated and well protected from mechanical injury, are run from the testing room to the terminal room or cable-tanks. It is best to terminate these leads at the testing table on a set of the insulated double binding posts described above; the ends of the leads are then protected from damage and the insulation afforded is excellent; the pillars can be numbered to avoid confusion and any lead can be connected with the testing instruments by simply joining a short piece of wire from the key to the binding post on which the lead required terminates.

Another very useful accessory on a testing table is illustrated in Fig. 28. It consists simply of a brass plate carrying a number of binding posts and serves for connecting the various instruments to earth. Connection with earth is required in several tests and the brass earth plate makes a very neat job of the connections, which, if made by simply twisting the wires together, would present anything but a

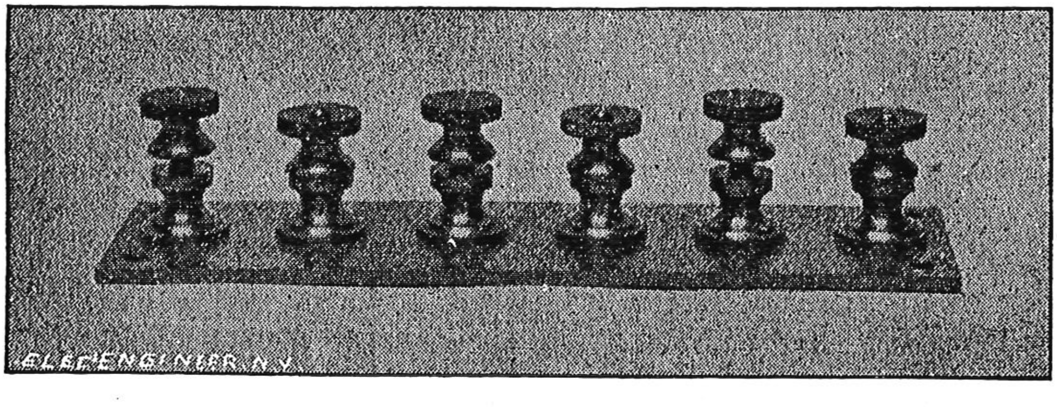

FIG. 28.—BINDING POSTS FOR EARTH CONNECTION.

sightly appearance, to say nothing of the risk of poor contacts. The end terminal of the plate is connected to a good earth by means of a substantial lead, and when it is necessary to put any of the keys or instruments to earth, the only operation requisite is to run a wire to one of the spare binding-posts of the plate.

An improvement I would suggest on this plate is that it be made in two parts, one part carrying the terminal to which the earth wire is connected and the other the remaining terminals for the instrument connections. The two sections of the plate could be connected or disconnected by the insertion or removal of a plug. It is sometimes necessary, as when testing two wires, looped at the distant end, for conductor resistance, to remove the earth connection, and the simplest method of doing this is by taking out a plug. If the wire is taken off the binding post it is apt to be overlooked afterwards and cause trouble, but the absence of a plug from its proper place is more noticeable.

CHAPTER IX.

Practical Testing.

The reader has now been introduced to the various instruments used for cable testing, and next in order are a few definite directions touching on the manner of using them so as to obtain useful results. What may be called the theory of the different tests, and the action that goes on during their application, have already been explained and illustrated diagrammatically in Figs. 1, 2, 3, 4, 5, 6 and 7. The diagrams that follow show the actual connections of the instruments for making the different tests, and a comparison of the two sets of diagrams should give a very clear idea of the subject of practical testing.

In the earlier diagrams, some of the keys and connections were omitted in order that the path of the current and its action might be made as clear and intelligible as possible, and the appearance of each pair of diagrams will therefore differ materially; but nevertheless no difficulty should be found in understanding the relations between them, and it has been my endeavor throughout to make explanations and descriptions, even at the risk of prolixity, so detailed and full that even those who have never seen a set of testing instruments (if such there be), might be able to derive a clear idea of how the work is done and what goes on during each test.

THE GALVANOMETER CONSTANT.

Before testing a wire for insulation it is necessary to take the constant of the galvanometer in order to obtain a value with which to compare the deflection given by the wire or cable. The connections for taking the galvanometer constant are shown in Fig. 29.

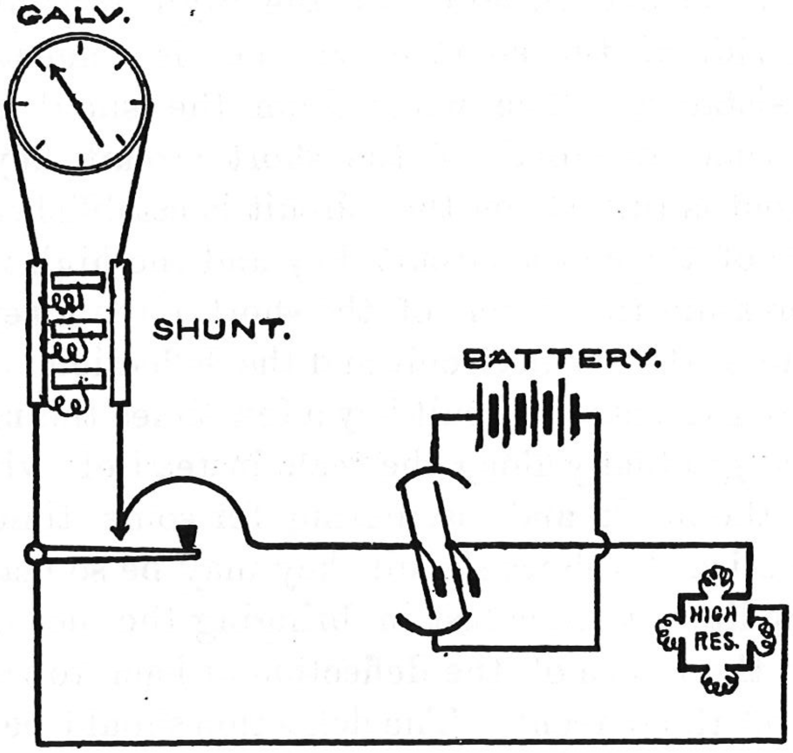

Fig. 29.—Connections for Taking Galvanometer Constant.

A high resistance of 100,000 ohms, or one megohm, is placed in circuit with the battery and galvanometer, which is shunted with the $\frac{1}{999}$th or $\frac{1}{99}$th shunt, and the deflection obtained by a steady application of the current is the constant of the galvanometer. The battery power should be the same as that used for testing the cable; or, if the galvanometer is so sensitive that, with the full battery, too large a deflection is obtained, half the number of cells may be used and the resulting deflection doubled. A better plan, however, is either to use a very high resistance or to shunt the galvanometer with a low resistance so that the full number of cells will give a readable deflection.

Tracing the connections in the diagram we see that one side of the battery key is connected to one terminal of the short circuit key, the other side of the battery key being connected to one terminal of the high resistance. The opposite side of the short circuit key is connected to the high resistance. The wires from the shunt are taken one to each terminal of the short circuit key. When the current is turned on the circuit is established through the lever of the short circuit key and the high resistance. On depressing the lever of the short circuit key the galvanometer is thrown in circuit and the deflection is obtained. By tapping the short circuit key a few times the needle will be moved gradually along the scale instead of swinging far beyond the mark and oscillating for some time; with a little practice the short circuit key may be so manipulated that very little time is lost in bringing the needle to rest, either at the figure of the deflection or back to zero before turning off the current. The deflection should be the same with both poles of the battery; if there is any appreciable difference the suspension is probably slightly twisted or the battery is inconstant, probably owing to bad insulation.

Assuming that the constant is taken with a battery of 100 cells, a high resistance of 100,000 ohms and a shunt in the galvanometer circuit of $\frac{1}{999}$th, and a deflection on the scale of 300 divisions is obtained, this result should be written down as follows:

Galvanometer Constant: 100 cells, 100,000 ohms, S $\frac{1}{999}$, def. 300=30,000.

The last figure, thirty-thousand, is the deflection that 100 cells would give through one megohm with no shunt in the galvanometer; or, in other words, 100 cells would give a deflection of one division on the scale through a resistance of 30,000 megohms.

To obtain the grand constant the deflection observed is multiplied by the power of the shunt used and by the resistance in circuit. In the case imagined the multiplying power of the shunt is 1,000 and the resistance $\frac{1}{10}$th of a megohm; consequently the grand constant is $300 \times 1000 \times \frac{1}{10} = 30,000$.

In noting down the galvanometer constant on a test sheet it is best to give all the details of number of cells, shunt and resistance employed, and the deflection obtained, in the form given above. If necessity should arise at any subsequent date for examining the report no doubt can then arise as to whether the same battery was employed throughout the test, or whether the constant was correctly calculated; and if all the data are properly noted down the test can be worked out again should there be any doubt as to the results; whereas, if these details are omitted there is no check on the correctness of the working or on the accuracy of the results given.

CHAPTER X.

Test for Insulation.

THE connections for the insulation test are shown in Fig. 30. It will be seen that almost the only difference between this and the preceding diagram is that the cable takes the place of the high resistance. In taking the galvanometer constant, however, it makes no difference whether one side of the battery key and high resistance are put to earth or connected directly together,* but in making the test for insulation one side of the battery must, of course, be put to earth, as it is the dielectric of the cable that really takes the place of the high resistance and the dielectric is in contact with the earth in the natural course of events.

Before the cable is connected to the lead the instruments and lead should be tested for leakage by turning on the the full battery power and opening the short circuit key, no shunt being inserted in the galvanometer circuit. If any deflection is observed it should be noted under the heading of "leakage from lead," and the amount of this deflection should be deducted from that given by the cable. It is important that all the instruments be kept clean and dry, and that the wire used for connecting them and for the lead have a high insulation. The leakage from the instruments and lead should not be more than a few divisions, ten at most; if much more than this is observed the connections should be overhauled, and the trouble remedied. It can readily be ascertained whether the leakage, if an undue amount is observed, is in the lead or the instruments by disconnecting the lead entirely and testing the instruments alone.

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*In Fig. 29, the connections are shown without earth.

Special attention should be paid to keeping the leads in good order ; the testing room ends, being connected to the insulated binding posts, need never be touched, but the ends that are joined to the cables or wires to be tested should be trimmed occasionally, the insulation being tapered so as to expose a considerable surface between the wire and the braiding ; the attendant who makes the connections should be instructed not to handle the lead near the extreme end but to hold it about six or eight inches back ; if the

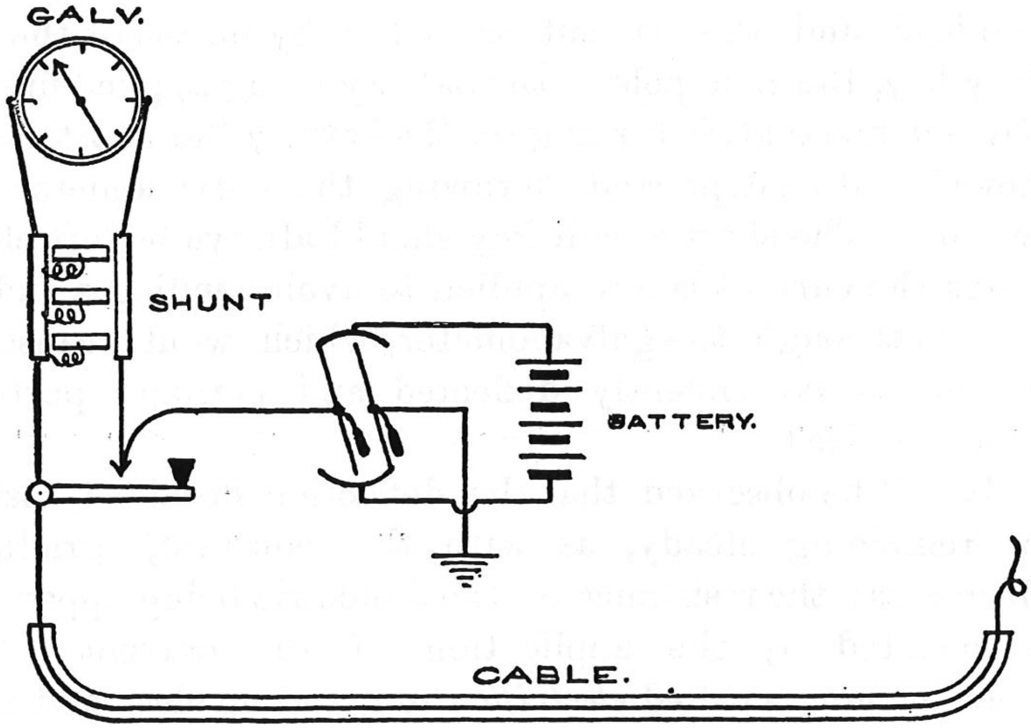


FIG. 30.—CONNECTIONS FOR INSULATION TEST.

end of the lead is handled much the insulation will become soft and perhaps damp, giving rise to surface leakage. When testing submarine cables, or wires submerged in a tank, both ends should be carefully trimmed and the insulation coated with hot paraffin for a short distance back to prevent surface leakage.

The insulation of the instruments and lead having been tested and found "O K," the cable is connected to the lead and the current turned on by means of the battery key, the zinc pole of the battery being applied first. A few moments after turning on the battery the short-circuit key should be depressed, throwing the galvanometer into circuit. The short-circuit key should always be left closed when the current is first applied to avoid sending a sudden charge through the galvanometer, which would cause the needle to be violently deflected and perhaps partially demagnetized.

It will be observed that the deflection obtained, instead of remaining steady, as with the constant, gradually decreases; the resistance of the dielectric being apparently augmented by the application of the current. This phenomenon is called *electrification*, and no clear and satisfactory explanation of its cause is forthcoming, although it is attributed to a sort of polarization of the insulating material by the action of the current. Electrification is especially marked with homogeneous dielectrics, such as gutta-percha and india rubber; it is greater with the latter, than with the former and with both materials it is greater at a low than at a high temperature.

With cables having a dielectric of fibrous material saturated with paraffin or resinous compounds electrification is very rapid for the first minute or two and subsequently very slow, or almost stationary. A cable of this description, if subjected to a temperature sufficiently high to lower the insulation to any considerable extent, will not show any electrification at all, the deflection remaining practically constant however long the current is kept on. A steady deflection and gradual electrification are signs of a good cable; absence of electrification, oscillations and kicks of the spot denote the reverse. In testing submarine cables, or rubber covered wires submerged in water, special attention should be paid to these indications. The deflection may be steady and show fair electrification, but if any sudden kicks are observed, even though they be very small ones, they may be taken as an almost sure indication that the wire or cable has an incipient fault which will probably be completely broken down, or at any rate developed sufficiently to proclaim its existence beyond doubt, by the steady application of the zinc pole of a battery of several hundred cells.

Another sign of a good cable is that it should give equal deflections with both poles of the battery. The zinc current is always applied first as it has the effect of accentuating any fault or incipient defect, and as a general rule the readings with the zinc pole are considered a sufficient indication of the condition of the cable; but if any weakness is suspected the cable is thoroughly discharged by being connected to earth for some time after the zinc current is discontinued, and a set of readings are taken with the copper pole of the battery to line. These readings should correspond with the first; if they do not—provided the cable has been completely discharged between the two applications of current—the test is not considered satisfactory and the cable will probably not last in good condition for very long.

These refinements in cable-testing are scarcely applicable to every-day work, but should always be applied when testing cables at a factory for acceptance or rejection, as the various points enumerated above throw considerable light on the specific quality of the dielectric and its prospective durability. It is not to be imagined that an relaxation of careful methods is advocated in every-day work, but it is not generally necessary in making periodical tests to take reversals or to take more than one minute's reading with the zinc current on each wire, except in the case of new cables or when a fault is suspected.

CHAPTER XI.

Test for Insulation.—(Continued.)

To return to our specific example of the test for insulation resistance. The behavior of the spot should be carefully watched, and at the end of one minute from the time of turning on the current the exact deflection should be noted. This deflection serves for working out the insulation resistance by comparison with the galvanometer constant; the figures for insulation resistance are generally stated to be "after one minute's electrification."

We will assume that the cable being tested is 2,640 feet long and that the deflection after one minute is 60 divisions on the scale. The constant of the galvanometer being 30,000, the absolute insulation resistance of the cable is $\frac{30000}{60} = 500$ megohms. As cables vary in length it is obviously useless, for purposes of comparison, to know the insulation resistance of a cable without also knowing its length, and even so it is not convenient to have to refer to two separate quantities; therefore it is usual to speak of the resistance per unit of length, and the insulation resistance per mile is the figure by which we can best judge of the actual condition of a cable.

In the present case the absolute insulation being 500 megohms and the length 2,640 feet, or .5 of a mile, the insulation resistance per mile will be $500 \times .5 = 250$ megohms. If the cable were 5 miles long and gave the same deflection, the insulation per mile would be 2,500 megohms.

The insulation resistance per mile is always found by multiplying the absolute insulation, or the insulation for the whole piece, by the length; if the length is less than one mile the insulation per mile will be less than the absolute; if the length is greater than one mile the insulation per mile will be proportionately greater than the absolute. Thus if a piece of wire one-tenth of a mile long showed an insulation of 10,000 megohms, its insulation per mile would be 1,000 megohms. If a cable 10 miles long showed an absolute insulation of 100 megohms its insulation per mile would also be 1,000 megohms.

In testing long submarine cables it is usual to keep the current on for a number of minutes, sometimes for half an hour, noting the deflection at the end of each minute. The electrification and general behavior of the cable under test can then be observed with care. After the zinc current has been on for thirty minutes, the cable is put to earth for five or ten minutes, and the discharge or earth readings are noted; then the copper pole of the battery is applied and a set of readings taken, after which the cable is again put to earth and the discharge noted at intervals as before.

With short cables it is scarcely possible to make such long tests unless the battery power employed is very great or the galvanometer extremely sensitive, as the deflection obtained from a short cable of high insulation is so small, that, at the usual rate of electrification, there would be no deflection at all, or else a stationary one, long before the thirty minutes' readings had been taken. Nor is it necessary to make such elaborate tests on short cables, as if there is any defect present it will be revealed by a few readings or by taking reversals, as previously explained.

In testing cables or wires insulated with homogeneous compounds in a factory they should always be immersed in water kept at a definite temperature during the whole time, not less than two or three days, that the cable is submerged previous to the test. The usual standard temperature to which cables are subjected to in factory tests is 75 deg. Fahrenheit. This is a higher temperature than they are likely to be affected by when in use, the conditions being purposely made unfavorable to the cable in order that any possible defects of manufacture, which might not show up at once under ordinary conditions, may be revealed before the cable is accepted and put into use.

In testing telephone cables containing 50 or 100 conductors it is necessary to test each wire separately for insulation and a certain number for capacity and resistance. As a general rule, one minute's reading is considered sufficient for each conductor, as a cable which practically depends upon the soundness of the lead sheath for its insulation will show very quickly whether the condition of the insulation is good or bad. Another reason which renders readings with different poles of the battery a poor guide to the condition of an underground cable insulated with fibrous material saturated with paraffin or compound, is that the insulation resistance is affected by heat to a very considerable extent, and it is also very quickly lowered by the presence of the smallest amount of moisture in the cable. But by whichever cause the insulation is lowered, the read-h opposite poles of the battery will be different, efore no clue is really afforded to the actual cause ısatisfactory test on a cable of this class ; it may : heat or moisture, unless, of course, there exists ute certainty that the cable is nowhere subjected ə heat. If, however, moisture once gains an in- o a cable insulated with fibrous material, the insu- ill fall very quickly and the entire cable will soon ically dead grounded, owing to the rapid absorp- noisture characteristic of such substances.

sulation of a telephone cable should be fairly regu- ghout, each conductor giving about the same in- but this is rarely the case, even when the average n is very high. For this reason the average of all uctors is always taken as a guide to the general n of the cable. A certain limit should be set, be- h no conductor is to fall, as the average insulation ıp to the mark owing to high results from a num- ıe conductors, while others may test so low as to the existence of a fault. As a general rule, if the n of a telephone cable is reasonably high and iform throughout, the condition of the cable is Vith a very high insulation there may be appar- eat irregularity between the different conductors, o the difficulty of reading very small deflections ıe ordinary conditions of testing ; if, for instance, lation varies from 5,000 to 10,000 megohms per ıay safely be assumed that there is nothing wrong; ver, the majority of the conductors show an insula- 500 to 700 megohms per mile, and about eight or uctors show a much lower insulation, ranging, say, from 30 to 100, although the average for the whole cable would be but slightly lowered by these few weak conductors, still they would indicate the existence of an incipient fault, which might in a short time develop sufficiently to seriously affect the condition of the whole cable. The uniformity of the test is therefore the best indication of the soundness of a cable of the description we are discussing.

In testing telephone cables for insulation all the conductors, except the one being tested, must be grounded ; otherwise some of the conductors, those toward the centre of the cable, will have the benefit of a greater thickness of insulation than the others. This is usually done by lacing a fine bare wire among the binding posts on the terminal head and connecting it to the iron box or to the lead pipe, sufficient slack being left in the wire for it to be pulled clear of each binding post in succession as the lead is connected.

One minute's reading with the zinc current is taken on each conductor and the insulation is worked out by the deflection obtained at the end of the minute, according to the method previously described. In calculating the average insulation of the cable, the deflections must not be added up and averaged, and the average insulation worked out by the average deflection ; the fairest method is to take the average of the insulation resistance of all the conductors.

To instance the different results given by the two methods if the deflections are at all irregular, let us assume that we are testing a cable 2,640 feet long. The constant of the galvanometer is found to be 30,000 and the first five wires give deflections after one minute's electrification of 30, 50, 30, 10 and 30 respectively. The average deflection would be 30, which would give an insulation of 1,000 megohms absolute and 500 megohms per mile. Working out the deflections separately, however, we get a different result:

No.	Deflection.	Insulation Resistance.	
		Absolute.	Per Mile.
1	30	1,000	500
2	50	600	300
3	30	1,000	500
4	10	3,000	1,500
5	30	1,000	500
Average Insulation,		1,320	660

Thus it is obvious that unless the deflections are extremely regular throughout, the average insulation should not be determined by the average deflection, as would readily occur to most, but by summing the insulation resistances of all the conductors and averaging. This would be very laborious if every conductor gave a different deflection but it generally happens that the same deflection occurs frequently in a test on a hundred-conductor cable, which considerably lessens the labor of working out the test and obtaining the average insulation.

In some cases it simplifies matters to work out results by logarithms. As an example, suppose the cable being tested is 3,475 feet long, and that we are working with a constant of 42,500. The first deflection after one minute's electrification is 37; to find the insulation absolute and per mile of this wire we proceed as follows:

$$\begin{array}{lll} \text{Log.} & 42{,}500 = & 4.62838 \\ \text{“} & 37 & 1.56820 \\ \hline & & 3.06018 = 1{,}148 \text{ megohms absolute.} \end{array}$$

Turning 3,475 feet into decimal parts of a mile we get .658; the log. of this added to the log. of the absolute will give the insulation per mile, thus:

$$\begin{array}{lll} \text{Log.} & 1{,}148 = & 3.06018 \\ \text{“} & .658 = & \bar{1}.81822 \\ \hline & & 2.87840 = 756 \text{ megohms per mile.} \end{array}$$

When dealing with large numbers it is no doubt more convenient to use logarithms, and, with one man to do the figuring and another to look up the logarithms and numbers, it is certainly quicker than working out by division and multiplication. It must always be remembered that in multiplying by logarithms the logs. are added, and in dividing, subtracted.

CHAPTER XII.

Testing for Insulation.—(Continued.)

It is important in testing a cable containing a large number of conductors, that the end of the lead be very carefully handled by the attendant who makes the connections, as, if the extreme end is touched or held frequently, the insulation is liable to become sticky and damp, causing an increase of leakage which would naturally be put down to the account of the cable, unless the lead were tried at intervals during the test, and any change in its condition noted and allowed for. A great deal of time also is consumed in changing the connections, unscrewing refractory nuts, tightening them up on the lead, etc. To obviate these difficulties a connecting clamp for joining on the lead wire to the binding posts of underground cable terminals has been devised, and is found to answer the purpose well, time being saved in changing connections, and the end of the lead being thoroughly protected. In Fig. 31, an illustration is given of this clamp in use; the clamp consists of a slit brass socket, the upper part of the socket being hinged and pressed towards the lower by a strong spring. The socket is attached to a hollow handle of hard rubber, and, the end of the lead being bent out straight, it is inserted in the handle, the end of the wire finding its way into a hole in the base of the brass socket, where it is held by a screw. The upper part of the socket or clamp is opened by pressing on the lever, which is faced with hard rubber, so that the attendant who makes the connections has no excuse for touching the lead at any uninsulated spot. In order to change a connection it is only necessary to remove the clamp from one binding-post to another; the pressure of the clamp on the binding-post makes a perfectly good connection, but the lead should be supported at a point near to the cable, or its weight hanging on the end of the connector will have sufficient leverage to force the spring back slightly, causing the upper jaw of the clamp to bear on the edge of the binding-post.

In testing a telephone cable it is advisable always to try the lead for leakage at the end of the test, and also to check the galvanometer constant; it is not unusual in buildings where machinery is sometimes running and sometimes stopped, for the sensitiveness of the galvanometer to vary, owing to the changed magnetic conditions. If the change is considerable and the deflections are regular, it will be noticed at once by the difference in the deflection; if the deflections are irregular the change in the galvanometer will probably be noticed by alteration of the zero, the spot sometimes going off the scale with a run without any apparent cause. After such an indication of altered magnetic surroundings a new constant should be taken at once. Such points as these, however, properly belong to each man's experience, and must be studied and provided for as they arise.

In testing for insulation the greatest degree of accuracy will be obtained by getting as large a deflection as possible; in this way closer readings can be made, and electrification or irregularities are more apparent. If a cable will give a deflection of 300, do not shunt the galvanometer so as to get a deflection of 30, under the impression that closer readings can then be made, as this is by no means the case. With short cables of high insulation it is necessary to employ a very sensitive galvanometer and a large number of cells in order to get a readable deflection, but if possible the battery should always be increased until a deflection is obtained that can be easily read, and that will allow of a certain fall due to electrification without getting within a few divisions of the zero mark.

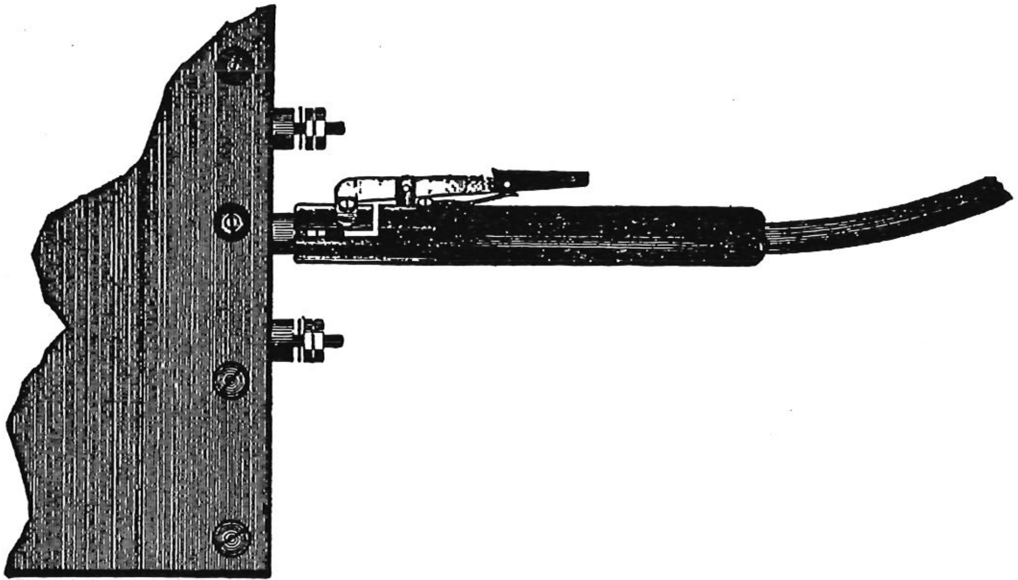

Electrical Engineer, N.Y.

FIG. 31.—CONNECTING CLAMP.

It is erroneously believed by some that the insulation of a wire or cable differs greatly with the tension of the current, testing or otherwise, and that a wire which gives a certain insulation when tested with 100 cells will give a much lower insulation when tested with, say, 500 cells, and that, consequently, tests should always be made with the same number of cells. This, however, is not the case, or at any rate it is held not to be the case by the best authorities; if the insulating material is sound the resistance will be practically the same whether the test is made with 50, 100, 500, or 1,000 volts. Of course with a greater E. M. F. there is a greater current flow, and therefore the deflection will increase with the number of cells. Consequently more battery power may be added with a view to producing larger deflections without any fear of conflicting results from tests made with a lesser or greater number of cells.

It must not be imagined from this, that a test with very small battery power is a good indication of the condition of a wire or cable. Quite the contrary. A wire may show a very good insulation when tested with five cells, although it may contain a fault, or more than one, which the application of, say, 100 cells would reveal very quickly. In the case of a weak or faulty wire, increased E. M. F., therefore, makes a difference, as there may be weak spots in the insulating material which would stand a stress of 5 or 10 volts, but which would give distinct indications of their presence under a stress of 100 volts, and would probably be broken down altogether by 500 volts. For this reason a test made with a battery of only a few cells is valueless, and equally for this reason it is now the custom in many factories to test cables intended for high-tension circuits with an E. M. F. somewhat greater than that which will be used on them in actual working. That they have stood this test once, however, is no indication that they will last good indefinitely and under all conditions, and such wires, whether overhead or underground, should be tested periodically and a close record kept of their insulation resistance; in this way only can warning be obtained of impending trouble, and the economical stitch in time applied at the right moment.

CHAPTER XIII.

Test for Capacity.

The usual method of measuring the inductive capacity of a wire or cable is to compare the charge it is capable of holding with the charge held by a standard condenser of known capacity, the same battery power being used for both operations. As already explained, an insulated wire or cable constitutes a condenser by itself, the wire being one plate and the outer covering or the earth the second, with the dielectric for the separating medium.

Insulated wires and cables have a high inductive capacity as compared with overhead wires, partly because the specific inductive capacity of the materials with which they are insulated is much higher than that of air, which forms the dielectric of an overhead line, and partly because they are laid on, or in, the earth, as the inductive capacity of a wire increases with its proximity to the earth. The inductive capacity of an overhead wire, strung at a height of about thirty feet above the ground, is more than twenty times lower than that of a heavily-insulated underground wire having a dielectric of rubber compound or gutta percha, and more than ten times lower than that of a conductor in an underground telephone cable having a dielectric of cotton and paraffin, or cotton and resinous compound.

It is very important to obtain accurate measurements of the inductive capacity of conductors used for telegraphy and telephony, as this quality of the wire has a distinct bearing on its usefulness; in telephony this is more especially the case, as every hundredth of a microfarad per mile counts for a good deal in limiting the range of transmission, especially where considerable lengths of cable are used in connection with long overhead lines.

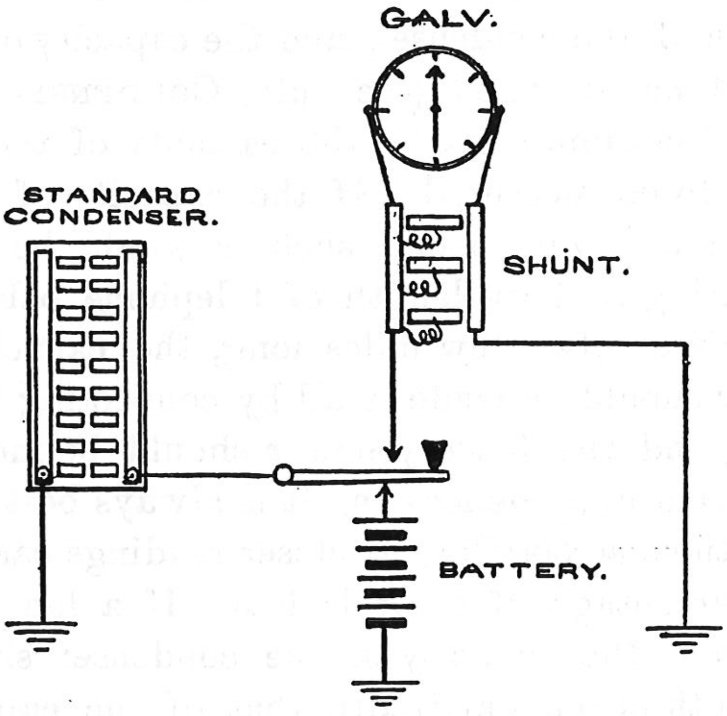


FIG. 32.

In Fig. 32 the connections for taking the discharge of the condenser are shown. The battery is connected to the lower contact of the discharge key, the condenser is connected to the lever of the key, and the galvanometer to the upper contact. The second pole of the battery and the other terminals of the galvanometer and condenser may either be all connected together, or put to earth.

By pressing the lever of the discharge key down, the condenser is charged to the potential of the battery, and by letting it fly up against the upper contact, the charge is released or neutralized and flows through the galvanometer, producing a sudden throw of the needle. This deflection should be noted; it corresponds, in a certain sense, with the galvanometer constant in the previous test.

From five to ten cells should be used in taking the discharge of the condenser, and the capacity of the condenser should be arranged (see ante, CONDENSERS) so as to have about the same value as the capacity of the wire or cable about to be measured. If the capacity of the wire to be measured is very small, such as would be the case when measuring a short length of telephone cable, or an overhead wire only a few miles long, the capacity of the condenser should be made small by connecting the sections in series, and the battery power should be increased so as to produce a large deflection. It is always best to get as large deflections as possible, as closer readings can be made and the percentage of error is less. If a long cable is to be measured the capacity of the condenser should be about one-tenth or one-hundredth that of the cable, so that the deflection given by the discharge from the cable with the $\frac{1}{9}$th or $\frac{1}{99}$th shunt in the galvanometer circuit shall be about the same as that given by the discharge from the condenser with no shunt. When possible, the use of shunts in capacity tests should be avoided, as a source of error is thereby introduced. There are instances, however, when it is necessary to take the discharge with the galvanometer shunted, as in the case of a long submarine cable.

Fig. 33 shows the connections for taking the discharge of the cable. The cable is connected to the lever of the discharge key, the other connections remaining the same, with the exception that here the second pole of the battery and the second terminal of the galvanometer must necessarily be connected to the earth.

It is usual to charge the cable for 15 seconds by pressing the lever down on the lower contact and keeping it clamped there by means of the trigger, for that time. The trigger is then pulled back, releasing the lever and allowing it to fly up to the upper contact, thereby discharging the cable through the galvanometer to earth.

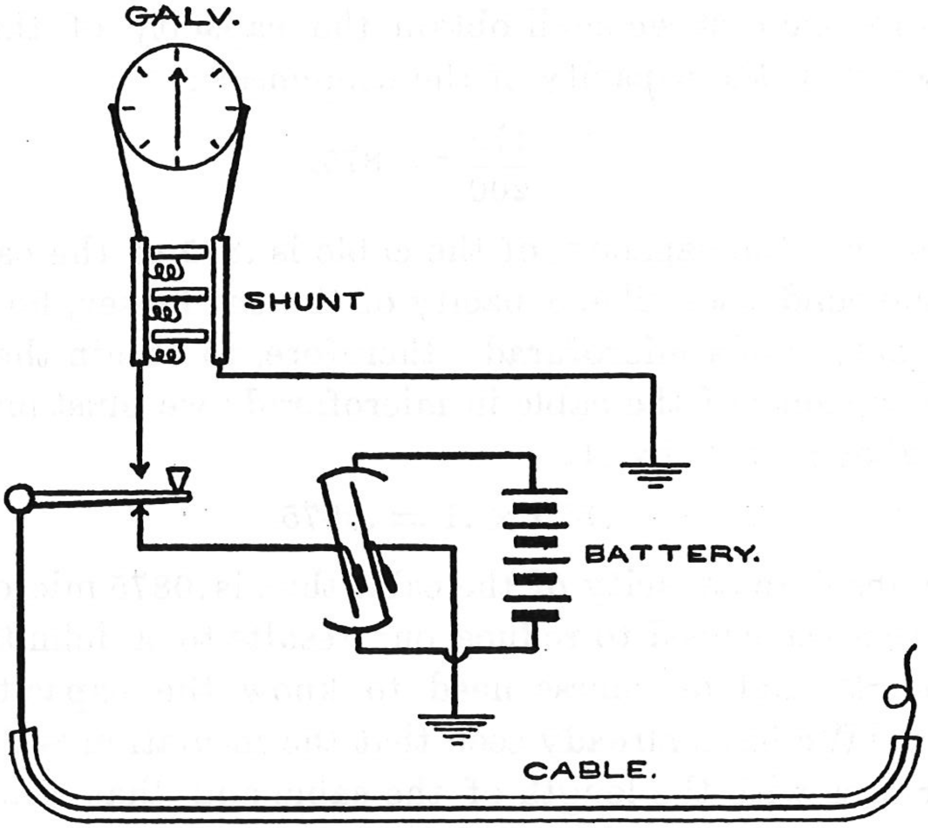


FIG. 33.—CAPACITY TEST, CONNECTIONS FOR CABLE DISCHARGE.

We will assume that the inductive capacity of a cable half a mile long is to be measured. By means of the plugs a section of .1 microfarad of the condenser is connected to the terminal blocks and the discharge taken with five cells of battery in the manner described. The deflection is 200 divisions of the scale. The cable is connected to the discharge key, and a discharge taken in the same manner. A deflection of 175 divisions is obtained. Now, the deflection of 200 was given by the discharge of a condenser of known capacity; therefore, if we divide the second deflection by the first we shall obtain the capacity of the cable in terms of the capacity of the condenser:

$$\frac{175}{200} = .875.$$

Therefore the capacity of the cable is .875 of the capacity of the condenser. The capacity of the condenser, however, was only .1 of a microfarad; therefore, to obtain the absolute capacity of the cable in microfarads we must multiply the above result by .1:

$$.875 \times .1 = .0875.$$

The absolute capacity of the cable then is .0875 microfarad.

We always need to reduce our results to a definite unit of length and of course need to know the capacity per mile. We have already seen that the insulation resistance decreases with the length of the cable and that the absolute insulation must be multiplied by the length in order to arrive at the insulation per mile. With inductive capacity the reverse is, of course, the case, the capacity of a cable increasing with its length. This is obvious, if we consider a cable as a form of condenser. One mile of a cable has a certain capacity, then two miles of the same cable will have twice the capacity, five miles five times the capacity and so on. Therefore, to determine the capacity per mile, the absolute capacity must be divided by the length. In this case the absolute capacity is .0875 microfarad and the length .5 mile.

$$\frac{.0875}{.5} = .175.$$

Therefore, the inductive capacity per mile of the cable being measured, is .175 microfarad.

The discharge from the condenser is often called the capacity constant, just as the constant of the galvanometer is often called the insulation constant. Neither expression is correct, but if they are used it should always be remembered that in working out a test for capacity the operations performed in working out the insulation are exactly reversed. For insulation, the constant is divided by the cable deflection to obtain the absolute, and, to obtain the insulation per mile, the absolute is multiplied by the length. For capacity the cable deflection is divided by the "constant" to obtain the absolute capacity, and to arrive at the capacity per mile, the absolute is divided by the length.

It must always be borne in mind that in dividing the discharge of the cable by the discharge of the condenser the result obtained is in terms of the capacity of the condenser employed. If a condenser of 1 microfarad capacity is used, the result will be in microfarads, but if the capacity of the condenser is $\frac{1}{3}$, $\frac{1}{10}$ or $\frac{1}{20}$ of a microfarad the result must be divided by 3, 10, or 20, as the case may be, in order to determine the capacity of the wire or cable in microfarads. Supposing a condenser of $\frac{1}{3}$ microfarad were used and gave a discharge of 120, and the cable gave a discharge of 150; then the capacity of the cable would be

$$\frac{150}{120} \div 3 = .4166 \text{ microfarads.}$$

If the cable were 1.5 mile long, then the capacity per mile would be

$$\frac{.4166}{1.5} = .277 \text{ microfarad.}$$

If we were to use a condenser of .05 microfarad capacity, and obtained a discharge of 75, and from the cable one of 100, then the absolute capacity of the cable would be

$$\frac{100}{75} \div 20 = .0666.$$

Supposing the cable to be 2,165 ft. long, or .41 of a mile; then the capacity per mile would be

$$\frac{.0666}{.41} = .1624 \text{ microfarad.}$$

When a number of wires are to be tested for capacity it is best to multiply the discharge from the condenser by the quotient of the value of the condenser, divided into one, which will give the discharge that would be obtained from a condenser of one microfarad capacity. Then dividing the discharges of the wires by this figure will give the absolute capacities directly in fractions of a microfarad.

If the condenser is adjusted to a capacity of .05 microfarad and gives a discharge of 75, by multiplying this discharge by 20, $\left(\frac{1}{.05}\right)$, we obtain 1,500, which is the discharge that a condenser of 1 microfarad would give with the same conditions of battery-power and galvanometer.

Then by dividing the discharge deflections of the wires by 1,500 we obtain their capacities in fractions of a microfarad. This method of calculation will be found more convenient than dividing in each case by the condenser discharge, and again by the capacity of the condenser.

In averaging the capacities of a number of wires of the same length (such as the different conductors of a telephone cable) when the deflections vary, it is not necessary to work out each deflection separately and average the results, as was shown to be the case in averaging the insulation resistance of a number of wires. The average capacity can be worked out from the average discharge deflection. The reason for this is simple and obvious. With the insulation test the constant is divided by the deflections, and if these vary much, the average of the results of each deflection worked out separately will not agree with the result obtained by working out the average of the deflections; it is advisable therefore to take the average of the insulation resistances of the various wires in order to state the average insulation resistance of the cable. In the capacity test, however, we divide the deflections by the condenser discharge, and the divisor therefore remains invariable. It is obvious that the average will be the same, whether it is determined by averaging the capacities of the separate wires, or by averaging the deflections and working out the mean deflection.

A simple example will serve to make this clear. Having from a condenser of .1 microfarad capacity obtained a discharge of 200 divisions, we take discharges on six wires in a cable, which give deflections of 240, 250, 250, 260, 240 and 260, respectively. Dividing by 2,000 we find their respective capacities to be .12, .125, .125, .13, .12 and .13 microfarad. The average capacity of the six will be .125 microfarad. Now summing the deflections we get 1,500, which, divided by 6, the number of wires, gives a mean deflection of 250. Dividing this by the condenser discharge 2,000 we obtain the same result, .125 microfarad, as the average capacity of the six wires.

In testing a telephone cable it is usual to test about twenty conductors for capacity; as the deflections will probably vary throughout by a few divisions, it is more convenient to obtain the average by working out the mean deflection, than by summing the capacities of the wires. When testing a telephone cable for capacity, all the wires, except the one being tested, must be grounded. A test made with the cable not grounded would show a lower average capacity, owing to the greater thickness of insulation surrounding some of the wires. This would not be the capacity of the cable under working conditions and the test would be worthless as an indication of the quality of the cable. In this type of cable it is sometimes desirable to test the capacity of a pair of wires, the ends being left disconnected at the further terminal of the cable, and the end of the second wire joined to one pole of the battery and the galvanometer, the earth connections being removed. The capacity of the loop will be one-half the capacity of one of the conductors, or one-quarter the capacity of the entire length of wire contained in the loop.

In making factory tests for capacity, when a long length of cable wound on a drum is to be tested, the sheathing of the cable should be grounded, the ground connection being made with great care, in order to avoid inductive action between the different turns. In testing single wire cables of considerable length for capacity, when the cable is coiled up, it is best to connect both ends to the discharge key. In this way the time of charging is reduced and the chances of error, by reason of induction from one turn to another, will be lessened by partially getting rid of the electro-magnetic retardation of the coils.

It is of the greatest importance in testing for capacity that the insulation of the instruments be practically perfect, and this is especially important in measuring the capacity of loops (*i. e.*, "one wire against its mate"), because, as no earth connection is used, any leakage from the instruments will make the capacity measured appear higher than it really should be.

CHAPTER XIV.

Test for Conductor Resistance.

THE principle of the Wheatstone bridge for measuring the resistance of conductors has already been explained, but may be appropriately recapitulated here. It consists, briefly, in offering two paths for the battery current, one along the conductor to be measured, and the other by the variable resistance; by connecting two points in these separate paths through a galvanometer or other instrument (such as a telephone) capable of indicating the existence of a difference of potential between the two points, the variable resistance can be intelligently manipulated until equal potential at the two points is reached; the resistances of the two paths open to the current are then equal, and the resistance of the conductor can be read by the value of the variable resistance in circuit. In referring to the schematic diagram given in the introductory chapter, the analogy employed was that of an ordinary balance, the arms of the bridge being the beam, the adjustable resistance the weights, and the galvanometer the pointer. This was assuming the arms of the bridge to be of equal value, as the two halves of the beam always are. But the bridge has a far wider range of measurement than this, which would limit our measurements to the total value of the resistance coils. Pursuing the analogy of the balance, the arms of the bridge, being adjustable, constitute a sort of reversible steel-yard, and by altering their ratio we can make our weights a thousand times heavier than they are by themselves, or a thousand times lighter, enabling us to weigh accurately with the same set of weights, either very heavy or very light bodies, or in other words, to measure very high or very low resistances. This property alone is sufficient to stamp the Wheatstone bridge as the most beautiful measuring instrument known to science.

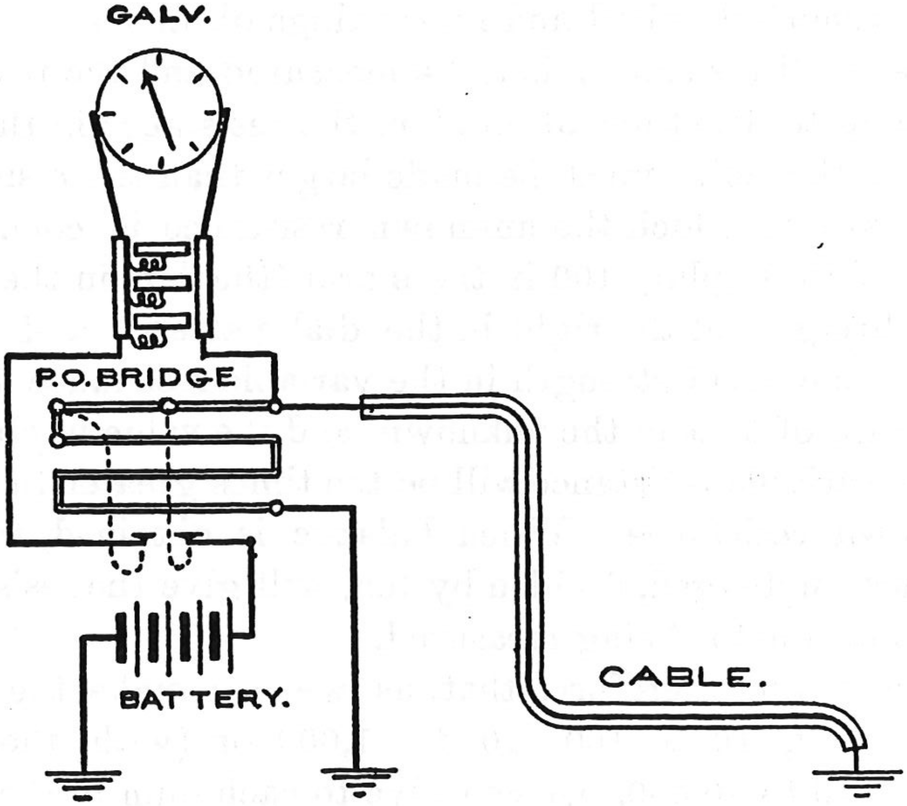


Fig. 34.—Connections for Resistance by Post Office Bridge.

As already described, the arms of the bridge each contain three coils having resistances of 10, 100, and 1,000 ohms respectively; some bridges have two additional coils of 10,000 ohms each, and bridges are occasionally made with five coils in each arm, the lowest of one ohm, and the highest of 10,000 ohms resistance.

If we desire to measure a resistance with an accuracy of one ohm only, the ratio of the arms must be equal, that is, two coils of equal value must be unplugged. In any case, two of the proportional coils must be unplugged when making measurements with the bridge, or the galvanometer will be short-circuited and no readings obtained.

If a small resistance is to be measured and the result is required to fractions of an ohm, the resistance in the arm nearest the coils must be made larger than the resistance in the arm to which the unknown resistance is connected. Thus, if we unplug 100 in the B arm (the left in the Post-office bridge and the right in the dial pattern) and 10 in the A, the current strength in the variable resistance will be one-tenth of that in the unknown, and the value unplugged in the variable resistance will be ten times greater than the unknown resistance. When balance is obtained, the resistance unplugged, divided by ten, will give the resistance of the conductor being measured.

It is plain, therefore, that, as we can make the ratio either way, 10 to 100, 10 to 1,000 or (with the dial bridge) 10 to 10,000, we can give to each ohm in the variable resistance a value of $\frac{1}{10}$, $\frac{1}{100}$ or $\frac{1}{1000}$ of an ohm, or a value of 10, 100 or 1,000 ohms, according to whether we are measuring low or high resistances.

A simple rule to remember, calling the arm nearest the coils *b*, and the arm to which the conductor to be measured is attached *a*, is: When measuring low resistances make *b* higher than *a*, and when measuring high resistances make *a* higher than *b*. In the Post-office bridge *b* is on the left when the keys are nearest to the manipulator ; in the dial bridge the ratio coils are placed in front of the dials and *b* is to the right. Fig. 34 shows the connections for measuring conductor resistance with the Post-office bridge, and Fig. 35 with the dial bridge. In these diagrams it is assumed that only one end of the conductor is available for connection to the instruments, the other being put to earth. In this case the end of the variable resistance, *i. e.*, the bridge coils, and one pole of the battery are also put to earth. The general similarity between these diagrams and that shown in Fig. 7, is easily apparent.

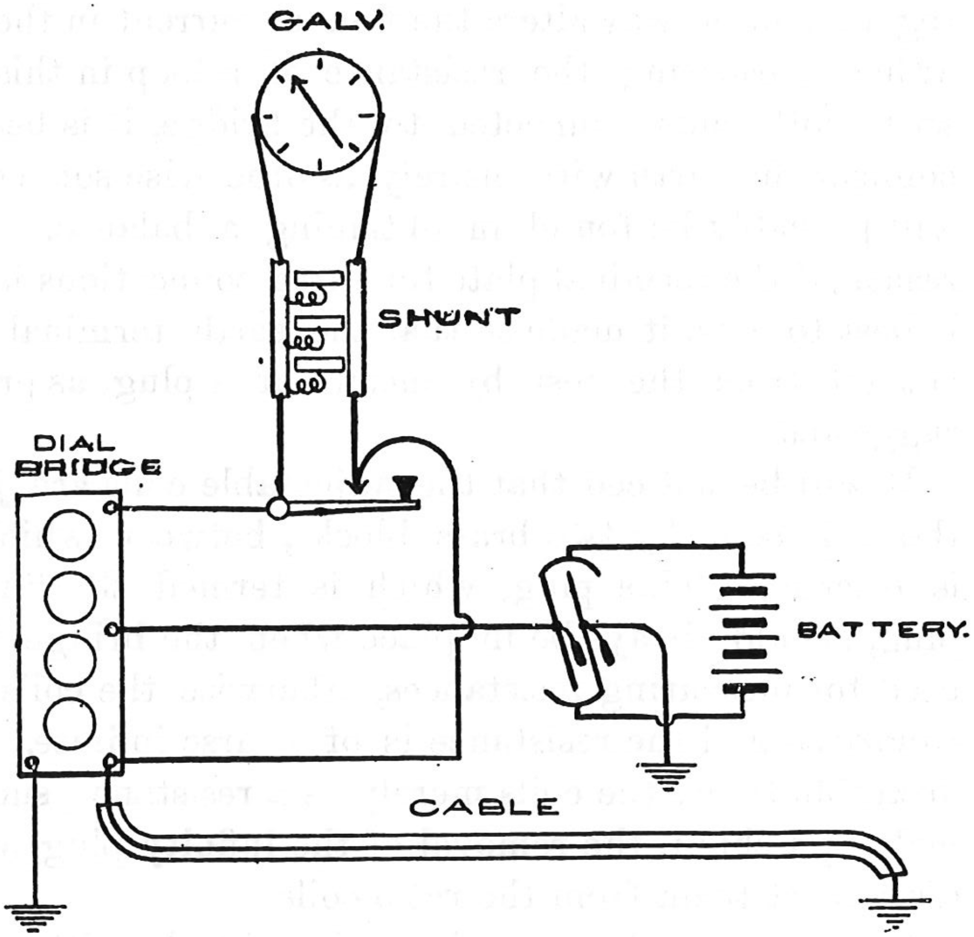


FIG. 35.—CONNECTIONS FOR RESISTANCE BY DIAL BRIDGE.

If both ends of the conductor to be measured are available, the second end is connected to the terminal of the coils, the second pole of the battery also being joined to the same point. As these three connections were all to earth in the previous case, it is obvious that joining them together in no way alters the flow of current in the system. When measuring the resistance of a loop in this manner with both ends connected to the bridge, it is best to disconnect the earth wire entirely, as otherwise some difficulty will probably be found in obtaining a balance. For this reason, if the terminal plate for earth connections is used, it is best to have it made so that the earth terminal may be cut off from the rest by means of a plug, as previously suggested.

It will be noticed that the adjustable coils are joined to the ratio coils by two brass blocks, between which a plug is inserted. This plug, which is termed the "infinity" plug, should always be in place when the bridge is being used for measuring resistances, otherwise the coils are *disconnected* and the resistance is of course infinite. If it is desirable to use the coils merely as a resistance, such as for making a shunt, the removal of the infinity plug serves to disconnect them from the ratio coils.

In the dial bridge there is a pair of blocks with a connecting plug at the end of each set of ratio coils. The plug to the right is the infinity plug and should be in place; that to the left should be removed when measurements are being made, or the conductor being tested will be short-circuited and balance made impossible. As a matter of fact, the coils being between the two terminals at the extreme ends of the brass blocks, either plug could be used as the infinity plug, provided that the unknown resistance were connected at the opposite end of the instrument, but it will be found more convenient in practice to keep to one method of connecting up.

The battery power employed for resistance tests need not be high unless the length of wire to be tested, and consequently its resistance, be very great. For ordinary measurements five cells of battery are ample.

The connections being made as indicated, the ratio coils should be adjusted according to whether the resistance to be measured be high or low, and the coils should be unplugged so as to throw in circuit an amount of resistance approximately equal to the unknown resistance. The galvanometer should be shunted with the $\frac{1}{99}$ or $\frac{1}{999}$ shunt to prevent violent throws of the needle if the balance is very uneven at first. Assuming that we are working with the Post Office bridge, the battery key should now be depressed and the galvanometer key tapped lightly, and the direction of the deflection observed. It will depend upon the battery and galvanometer connections whether a movement of the spot to the left indicate too high or too low resistance in the coils, but this can readily be ascertained by varying the resistance considerably and noting the result. If the movement be at first to the left and the addition of a number of ohms result in a deflection to the right of the zero, then to the left means not enough resistance in the coils, and to the right, too much. These indications will, of course, have opposite meanings when the battery is reversed. It is usual to put the zinc or negative pole to line, but in testing a wire of any length with one end to earth it is necessary to take a number of readings with both currents, the mean of all the readings being taken as the resistance of the line. This method is required on account of the earth currents which occur in long lines connected to the earth, and which modify the apparent resistance of the wire when measured with different poles of the battery to line. In a long submarine cable having a total resistance of several thousand ohms, the difference between the resistance measured by the zinc current and the resistance measured by the copper current will be sometimes as much as one thousand ohms, but the mean of a number of readings made with each pole to line alternately, will give the correct resistance of the cable.

The battery key being held down and the galvanometer key tapped from time to time to ascertain whether to increase or diminish the adjustable resistance in circuit, the adjustment can rapidly be made by manipulating the plugs until the spot remains on the zero of the scale. When balance is nearly effected, the shunt should be decreased, and finally removed altogether, so as to obtain the maximum sensitiveness of the galvanometer in arriving at the final balance.

As a general rule in measuring the resistance of land lines, whether overhead or underground, the distant ends of two wires are joined together and the resistance of the loop is taken. The resistance of each wire is then half the resistance of the loop. This, of course, is only permissible when the two wires are of equal length and of the same diameter.

If the conductors to be measured are connected to the instruments by long leads, the resistance of the leads should be measured, their ends being connected together and the test made in the manner described above. The resistance of the leads must be deducted from the observed resistance of the wire or cable being tested.

In measuring the resistance of a long line where only one end is available, the distant end being put to earth, several readings should be made with each pole of the battery to line; the mean of the several readings will give the actual resistance of the wire. In measuring the resistance of a loop or metallic circuit, a single reading with either pole of the battery will be sufficient; no connection being made with the earth, there is no chance for earth currents to affect the readings.

By referring to Fig. 35 (see p. 195), it will be seen that the dial bridge, besides having the advantage of a greater range of resistance, is somewhat more convenient to use (where the instruments are permanently set up) than the Post Office pattern, although the latter has no equal as far as portability and compactness are concerned. With the dial bridge the ordinary battery key is used, and the battery can be turned on and kept on without the necessity of holding down a spring key, and the battery can be reversed when requisite without any trouble. The wires from the ends of the proportional coils are connected to the short circuit key of the regular set of instruments, and by means of this the galvanometer is opened and closed for observing the progress toward effecting a balance. There are fewer plugs to manipulate, and the amount of resistance can be read directly from the dials. This renders work somewhat quicker than with the Post Office bridge. A very quick acting dial bridge is made by having a revolving arm pivotted to the block in the centre of the dial, the under surface of the arm making a rubbing contact on the sectional blocks. In this way plugs are dispensed with altogether and measurements can be made with great rapidity owing to the extreme ease with which the adjustment can be made. Such an arrangement, however, is open to the objection that resistance might be introduced at the contacts owing to wear at the bearing of the revolving arm, and insufficient pressure between the lower surface of the arm and the blocks. The possible error from these causes, if the instrument is thoroughly well made, should be very small, and where very great accuracy is not absolutely essential, a bridge of this type would no doubt meet with much favor, owing to the saving of time effected by its use.

The operation of measuring the resistance of a conductor is a very simple one, and a practical example will suffice to explain the method of proceeding. We will assume that the resistance of a wire five miles long is to be measured. If the end of the wire is directly available it is connected to the bridge at the end of the proportional arm, or, if a lead is used the resistance of the lead is taken first. The lead is found to measure .36 of an ohm. The wire is then connected and a certain amount of resistance is unplugged in the coils, approximately equal to what we believe the resistance of the wire to be. This resistance being a comparatively low one, the proportional coils are unplugged in the ratio of 10 to 100, 10 in the arm next the cable and 100 in the arm next to the adjustable coils. In this way the resistance in the coils will be ten times that of the cable, and we can make the measurement with greater accuracy. The galvanometer should be shunted, as probably the first trial will not nearly give balance and there will be a rush of current through the galvanometer causing a violent deflection when the short-circuit key is opened. The key should be lightly tapped, and not held down until balance is nearly obtained. Having plugged 1,500 ohms in the adjustable coils, we find on tapping the short-circuit key that this is not enough, and more resistance is added until the deflection is lessened and finally commences to rise on the opposite side of the scale. As we approach a balance the shunt is removed, giving the maximum sensitiveness of the galvanometer. When the deflection begins to be on the opposite side of the scale the resistance in the coils is slightly decreased and balance is obtained, *i. e.*, the spot remains on the zero mark, with the short-circuit key held open, with 1,745 ohms resistance in the coils. The resistance of our cable is therefore 174.5 ohms; subtracting .36 ohm, the resistance of the lead, we get 174.14, and, dividing by five, we find that the conductor has a resistance per mile of 34.828 ohms.

When possible, as in measuring the resistance of wires in cables containing a number of conductors, it is better to join a pair of wires together at the distant end and take the resistance of the loop. The two ends are connected to the bridge, and the two battery wires also, all ground connections being dispensed with. The figures obtained must, of course, be halved to give the resistance of a single conductor.

CHAPTER XV

Connections of Permanent Set of Testing Instruments.

In Fig. 36 is shown a diagram of a complete lay-out of testing instruments for use in the testing room of a wire factory, electric-light, telephone or telegraph central station. The instruments required have already been fully described, and in describing the lay-out and connections it is only necessary to briefly enumerate them once more, as follows:

Astatic reflecting galvanometer with box of shunts, lamp stand and scale.

Galvanometer reverser.

Short circuit key.

Discharge key.

Battery reversing key.

Wheatstone bridge (for permanent use, preferably of the dial pattern).

High resistance box, 100,000 ohms or one megohm.

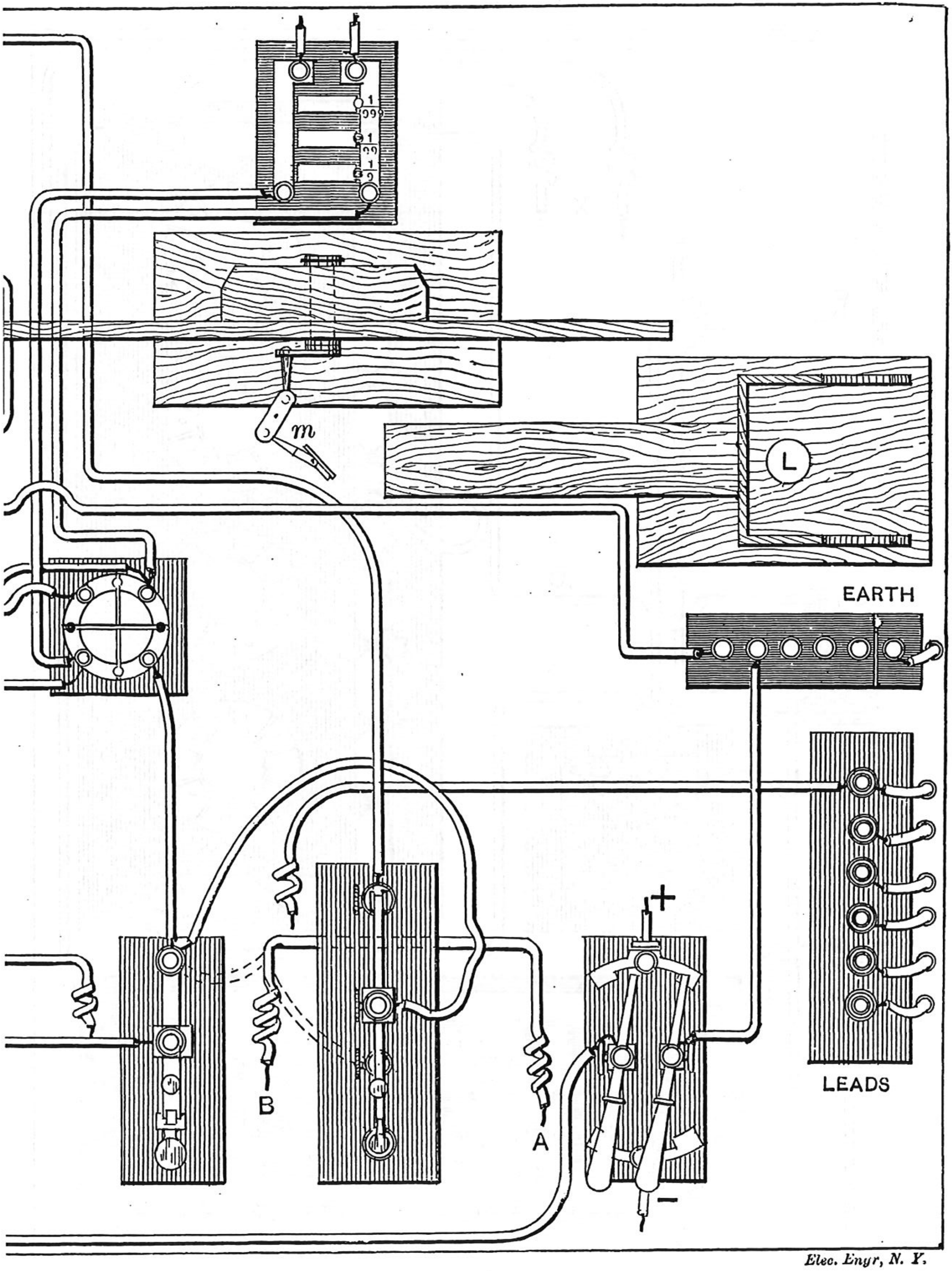
Adjustable condenser.

100 cell testing battery.

Set of insulated double binding posts for attaching leads running to factory or cable terminals.

Set of single binding posts on brass plate for earth connections.

In the diagram all these instruments are shown, with the exception of the galvanometer and battery; their po-



1/999
1/99
1/9
m
L
EARTH
LEADS
B
A
+
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Elec. Engr, N. Y.

MPLETE LAY-OUT OF TESTING INSTRUMENTS.

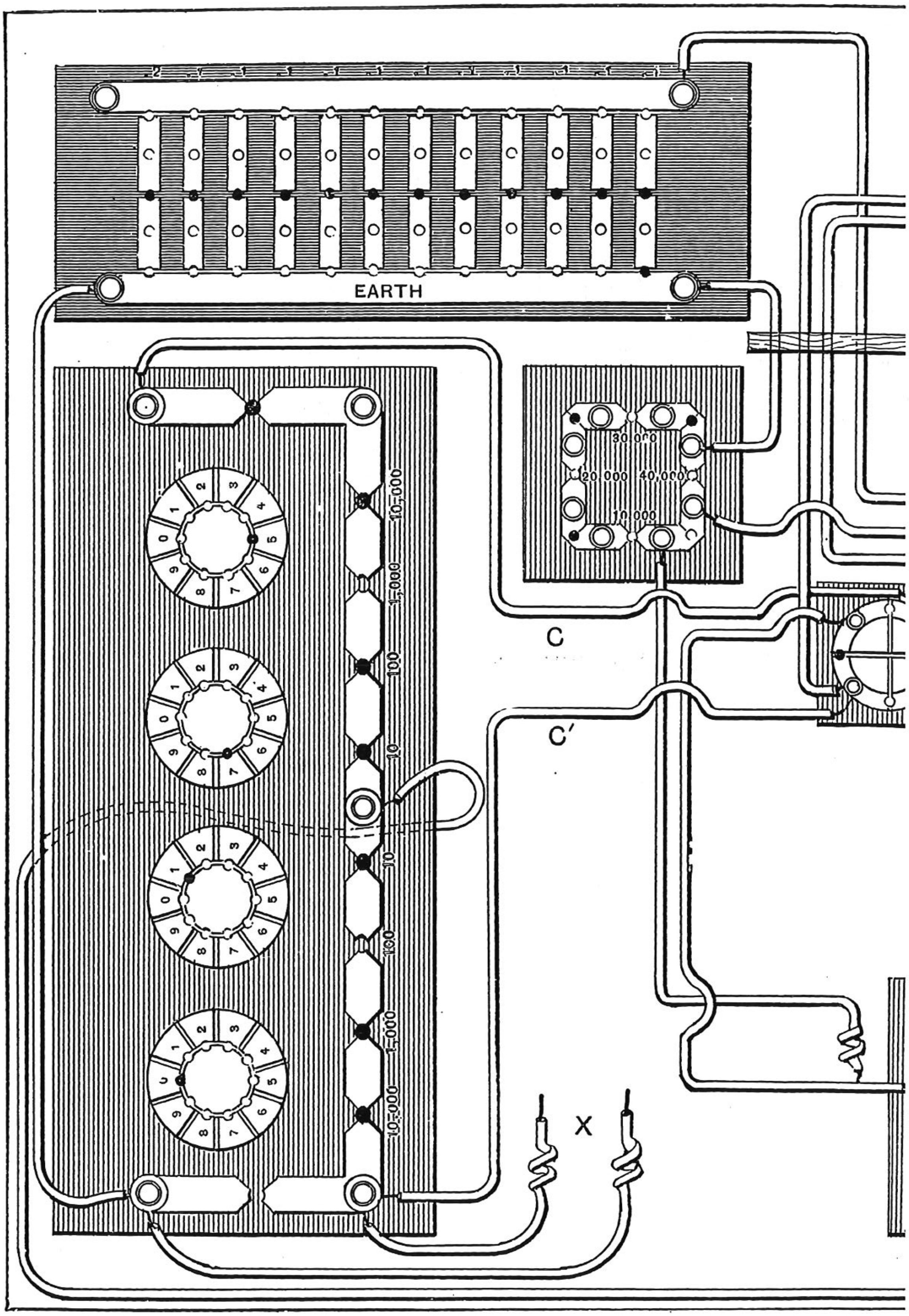

EARTH
30,000
20,000
40,000
10,000
10,000
1,000
100
10
10
100
1,000
10,000
C
C′
X

Fig. 36.—Diagram of Complete La

sitions, however, are sufficiently well indicated by the leads from the shunt and battery reversing key. The omission of the galvanometer and battery allows of greater clearness and compactness in the diagram. The diagram shows the most convenient method of placing and connecting the instruments on the table ; the galvanometer would be set upon a shelf removed a short distance from the table and the battery on another shelf, either behind the table, at the side of the manipulator, or underneath.

Starting from the right hand lower corner of the table, we find the set of insulated double binding posts on which the leads running to the cables are terminated. Immediately above this is placed the brass plate with a number of single binding posts ; this plate serves for connecting the instruments together or connecting them to earth, a stout wire being run from the end post to a good earth. The improved form of plate is shown with the end post divided from the rest of the plate, so that the ground can be taken off by removing a plug. This arrangement is useful when testing a looped wire for copper resistance, as the presence of a ground will often prevent a balance being obtained.

Above the earth plate is placed the lamp stand, from which projects a wooden channel directing the light to the mirror at the back of the scale, by which it is reflected to the galvanometer. The scale is of the ground-glass pattern previously described. Next to the set of insulated binding posts is the battery reversing key, of the Rymer-Jones pattern. One pole of the battery is connected to each of the crescent-shaped contact pieces at either end of the key ; the right hand lever is connected to earth by a wire run to the earth plate. Near the left hand lever two wires are terminated, being attached to the table and spiralled so that either can readily be connected to the binding post on the left hand lever. One of these wires goes directly to the centre binding post of the bridge ; the other is terminated between the short circuit and discharge key, and spiralled so that it can be connected to either key —to the short circuit in taking the galvanometer constant, or in testing for insulation ; and to the discharge key for capacity tests. So much for the battery connections.

Next to the battery key is placed the discharge key, and next to this the short circuit key. The short circuit key is permanently connected to the galvanometer reverser by two wires, and a short wire is run from one post of the short circuit key to the upper contact of the discharge key. At the back of the discharge key is terminated a wire from the condenser, which can be connected to the lever of the key for taking the discharge of the standard condenser. In the same manner a wire from the high resistance is terminated near the short circuit key, available for being connected to the binding post of the key opposite to that to which the wire from the battery key is attached. A short wire led from the insulated binding posts to a point between the short circuit and the discharge key serves for connecting any of the leads to either key for insulation and capacity tests.

The bridge is placed at the extreme left of the table ; above it and at the rear of the table is the multiple-series adjustable condenser, and in the angle between the two the high resistance box used for taking the galvanometer constant.

We have already seen that one wire runs direct from the battery key to the centre binding post of the bridge, another wire from the discharge key to the condenser, and still another from the short circuit key to the high resistance; the other connections of these instruments are as follows: From the extremities of the bridge arms two wires are led to the galvanometer reverser, and spiralled so as to be readily attached to opposite segments of the reverser. It would be the same thing to take these wires to the short circuit key; but as this would overcrowd the wires in that neighborhood, it is more convenient to take them to the reverser.

To connect the unknown resistance to the bridge, two wires are led from the binding posts on the brass blocks at the left of the bridge; the infinity plug being out, one of these posts constitutes the extremity of one of the proportional arms, the other the extremity of the adjustable resistance coils. The two wires are preferably taken to the extreme right hand corner of the table and terminated and spiralled there, ready to be connected to a pair of the leads attached to the insulated binding posts. For greater clearness they are shown in the diagram just to the right of the bridge at x, as if for connection to a coil whose resistance is to be measured. The remaining connection of the bridge is from the end of the adjustable coils to earth or to the second pole of the battery; the condenser and high resistance also require to be connected in the same manner; and to simplify the wiring, a wire is run from one of the binding posts of the high resistance to the earth plate. The extremity of the bridge coils is connected to the "earth" block of the condenser, and this, in turn, is connected to the high resistance by another short piece of wire. In this manner the return circuit of the bridge, condenser, and high resistance, is effected with the greatest economy of wiring and connections.

The usefulness of the earth plate here shows to advantage ; one lever of the battery key being permanently connected to it, the connections to one side of the other instruments can also be made permanent, and the plate serves both as a junction for the bridge, condenser, high-resistance and battery wires, and as a handy connection to earth whenever such a connection is required.

The galvanometer reverser is permanently connected to the shunt, and the shunt to the galvanometer. The position of the shunt is a trifle inconvenient, but it is best placed as near as possible to the galvanometer, or error may be introduced by the resistance of the leads between the shunt and the galvanometer. In any case, very thick leads should be used for this purpose.

The lay out of instruments and connections described above will be found very convenient for arranging a set of instruments for permanent use in one place. A table four feet by three accommodates the entire set, as shown in the diagram, a clear space being left between the short circuit key and the bridge, for placing the note book or test-blanks.

The diagram shows the instruments connected for measuring conductor resistance ; as will readily be seen, the alterations to be made, in order to connect the instruments for any of the other tests, are very simple. To take the galvanometer constant the bridge wires are removed from the galvanometer reverser, and the bridge battery wire from the battery key. The short wire A B is then connected to the battery key and to the rear terminal of the short circuit key, the wire from the high resistance being attached to the front binding post of the short circuit key. The connections for taking the constant are then complete; the only change required to connect for insulation is to substitute, on the front binding post of the short circuit key, the short wire running to the leads for the wire connected to the high resistance.

To connect for taking the discharge of the condenser, the B end of the wire A B is removed from the short circuit key to the underneath contact of the discharge key, and the condenser wire is connected to the lever of the key. The short circuit key is held open by the catch, thus insulating the front contact, and the short wire which joins the two keys then serves to connect the upper contact of the discharge key with one wire of the galvanometer. The other side of the galvanometer must, of course, be connected to the earth plate, and this is done by running a temporary wire from one segment of the galvanometer reverser to the high resistance, which, as previously shown, is permanently connected to the earth plate. This completes the connections for capacity, and to take the discharge of the cable merely requires the connection of the piece of wire joining the lead to the rear binding post of the discharge key, in place of the condenser wire. With the instruments and connections laid out in the manner shown and described, the changes from one test to another can be made very quickly and without any confusion. Most of the wires are fastened to the table, but some, such as the wire from the discharge key to the condenser, and those from the bridge to the condenser, battery and leads, can be carried underneath the table, or under the projecting ledges.

CHAPTER XVI.

General Remarks.

In working with portable sets the following simple rules for connecting up will be found of use:

Galvanometer Constant:—Connect one pole of battery to galvanometer, second pole of battery to high resistance, second terminal of galvanometer to second terminal of high resistance; shunt and short circuit key to be bridged across galvanometer circuit.

Insulation:—Connect one pole of battery to galvanometer and the other to earth; join the cable to second terminal of galvanometer; shunt and short circuit key as before.

Condenser Discharge:—Connect "earth" block of condenser, one terminal of galvanometer and one pole of battery together; front block of condenser to lever of discharge key, second terminal of galvanometer to upper contact, and second pole of battery to lower contact of discharge key.

Capacity of Cable:—Connect one pole of battery and one terminal of galvanometer to earth, substitute the cable or lead for condenser at lever of discharge key; other connections the same as in taking discharge of condenser.

Conductor Resistance:—If cable to be measured is single and grounded at distant end, connect as follows: Join one pole of battery to centre of proportional arms of bridge and other pole to earth. Connect cable to extremity of left hand proportional arm, and extremity of adjustable coils to earth. One terminal of galvanometer is connected to extremity of each proportional arm.

If the cable to be measured is double and looped at the distant end, the only difference in the connections will be to join second cable-end and second pole of battery to extremity of adjustable resistance coils, removing the earth connection at this point.

In setting up the instruments the first operation will always be to connect the shunt to the galvanometer, and the short circuit key to the shunt; when this is done the terminals of the short circuit key correspond practically to the terminals of the galvanometer; therefore all galvanometer connections are most conveniently made direct to the short-circuit key. When a galvanometer reverser is used it is best placed between the shunt and short circuit key.

CARE OF INSTRUMENTS AND CONNECTIONS.

In connecting up instruments either for temporary or permanent use, trim the ends of all wires carefully, tapering the insulation back from the bared portion of the wire, so as to leave no loose shreds of insulation or braiding to make contact with binding posts or other parts of instruments and thus give rise to surface leakage. Always bend wires around binding posts from left to right, so that when the nut is screwed down it will tend to grip the wire firmly and not to loosen it or push it back, as would be the case were the wire bent round from right to left. This point is one of special importance when dealing with stranded wire.

Keep the hard rubber pillars, bases and tops of keys and other instruments thoroughly dry and clean. It is very difficult to prevent dust from lodging on the instruments, as some of the parts are very difficult to get at, but a little careful attention every day with a camel's hair brush and a piece of chamois leather will go a long way toward keeping the instruments in good condition and always looking clean and bright. When not in use the instruments should always be properly covered up. If work is being done every day it is better to dust twice a day—in the morning before beginning work and in the evening before covering up. In any case the morning inspection and dusting should never be omitted.

When the instruments are not in use, all plugs should be kept in position to prevent dust from being deposited in the sockets ; dirty plugs and sockets introduce extra resistance. The plugs should be cleaned occasionally with very fine emery paper. The sockets should also be cleaned from time to time in the same manner. This can be done by means of a small wooden plug of a size to fit loosely in the socket ; by slitting the plug part of the way up, the edge of a strip of emery paper can be held in the plug and the strip wound round it. With this the sockets in the brass blocks can be thoroughly cleaned. If the plugs and sockets are kept clean there will be no danger of introducing extra resistance from bad contacts and accurate measurements can be depended upon. The platinum contacts of the keys should be cleaned occasionally by rubbing with a piece of ordinary unglazed writing paper, or, if they have become very dirty, with very fine emery paper. Keys with rubbing contacts will seldom need this attention, as the contacts are kept clean by the friction of the two surfaces. When ordering keys it should be insisted that all the fixed parts of brass be secured to the hard rubber pillars by means of steady-pins. If the steady-pins are omitted, the levers, contact plates and bridges will soon work loose and shift round—a very annoying and troublesome defect.

The bases of keys and other light instruments are generally drilled at the corners so that they may be screwed down to the table. A better plan, which will insure more thorough insulation, can be adopted if the instruments are to be used permanently in one place. This is to have the bases made solid, *i. e.*, without holes, and to stick the keys to the table with Chatterton's compound, or some similar elastic glue. In damp places the insulation of the instruments can be improved by covering the table with a sheet of gutta percha before setting up the instruments.

CHAPTER XVII.

Records and Reports of Tests.

In keeping records and making reports of tests for future reference, or for the information of others, care should be taken to make the information recorded as full as possible, so that all the data that can possibly be required at any future time may be always accessible. In making reports or entering up records of tests there can be no greater error on the part of the observer than to imagine, because certain data are quite well known to him, that there is no necessity to write them down, as he can always remember all about the matter himself. The object of keeping records and making reports is to furnish other persons with full information on the subject; and the records should be so written up that anyone needing to refer to them five, ten or twenty years after, might be able to readily ascertain the whole history of any cable tested, the conditions under which the test was made, and, if he found it desirable so to do, to check the figures and work out the test for himself.

This can only be made possible by inserting in the records all the details of the construction of the cable, such as size of the conductor, style and thickness or weight per mile of insulation, length of cable, etc., and all the figures referring to the test, such as battery power, resistance and shunt used in taking the galvanometer constant, battery power and shunt used in taking insulation test, leakage from lead, resistance and capacity of lead, capacity of condenser and battery power used in taking discharge from standard condenser. The state of the weather and the temperature should also be noted. When these data are all correctly given, a record of a test has permanent value; when they are omitted or given incorrectly, or in such form as to leave room for doubt as to their exact meaning, the record is almost useless for reference, as little dependence can be placed on a "bald and unconvincing tale" in which results only are given.

Another bad practice in writing up records, almost as reprehensible as that of suppressing information, is that of using abbreviations which are understood only by the inventor or abbreviator. All remarks should be written in plain English, and, where abbreviations are used, they should be only such as are customary and "to be understanded of the common people."

In making a report of a new type of cable it is necessary to enter more into detail than in reporting the test of a cable of well-known and frequently used description, particularly if the new cable is supposed to embody any special advances over previous methods, or if valuable advantages are expected to be derived from its adoption. In such a case it is necessary, besides giving a full report of the electrical tests, to make a detailed description of the mechanical construction of the cable, specifying the number, size and weight per mile of conductors; the nature of the insulating material, and the thickness and weight per mile on each conductor; the method of laying-up the conductors; style and amount of material used for outer protection; weight of complete cable per foot or mile, etc. Reports of this kind will, of course, vary in each case, but the point is that it should always be borne in mind that an electrical test alone does not give sufficient data on which to base an opinion of the merits of a new type of cable.

When the report deals only with a test on a cable of standard type, there is no necessity to enter all the mechanical details; it will be well to consider, however, the entries which should always be made, and these will serve as a guide for drafting forms for test blanks and record books.

Topographical Data:—Name or number of cable, location of terminals, and length of cable.

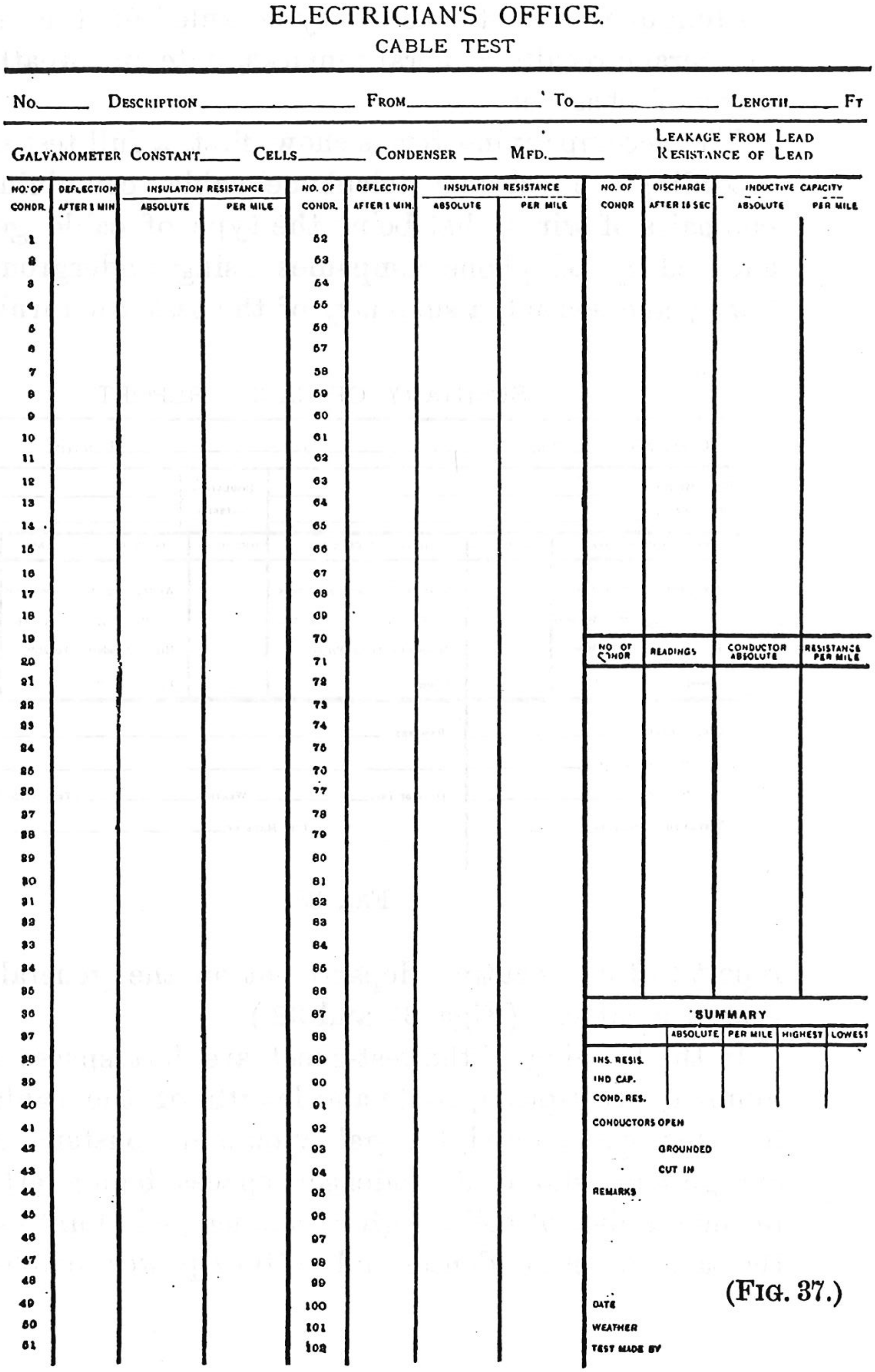
Mechanical Data:—Type of cable, manufacturer's name, number of conductors, size of conductors, thickness of insulation, description of insulating material, description and thickness or weight of outer covering. In some cases the name of the cable, if some conventional trade name is used, will be sufficient to indicate by whom the cable is manufactured, and also its general mechanical construction, as such cables are generally made to a standard specification which is only departed from when improved methods of manufacture render it necessary or advisable to amend the specifications.

Electrical Data:—Galvanometer constant, stating battery power, shunt and resistance used and deflection obtained. Leakage from lead taken with full battery. Discharge from lead taken with same number of cells as used in capacity test. Resistance of lead. Discharge from standard condenser, stating battery power, capacity of condenser used and deflection obtained. Deflection for insulation on each conductor and insulation resistance, absolute and per mile. Discharge deflection on each conductor and capacity, absolute and per mile. Resistance of each conductor (or loop) with lead, absolute resistance (lead deducted) and resistance per mile.

General Remarks:—Make note of any conductors open or grounded, number of working wires in cable, or anything in the condition of the cable likely to affect the test. Note the condition of the weather and the temperature of the air, and of the hydrant water if the cable is laid underground or of the tank water if the test is made in the factory. Note the date of the test and name of the person who makes it.

It is useful in the case of a cable containing a number of conductors to add a summary giving the average insulation resistance, capacity and conductor resistance of all the wires tested, and the highest and lowest results in each test. This shows at a glance the general condition of the cable.

In preparing a test sheet for filling in the above information, the heading should contain the spaces for the description of the cable, route, location of terminals, length, mechanical details, etc. Immediately below should be the spaces for galvanometer constant and condenser discharge, and particulars of the lead, *i. e.*, its leakage discharge and resistance. The rest of the sheet should be ruled in vertical columns for insulation resistance, inductive capacity and conductor resistance, a column being made for the conductor number, another for the deflection or reading, a third for the absolute, and a fourth for the per mile. At the



ELECTRICIAN'S OFFICE.

CABLE TEST

No._____ DESCRIPTION ________________ FROM ______________ TO ______________ LENGTH _____ FT

GALVANOMETER CONSTANT ____ CELLS ______ CONDENSER ___ MFD. ______

LEAKAGE FROM LEAD
RESISTANCE OF LEAD

NO. OF CONDR.	DEFLECTION AFTER 1 MIN.	INSULATION RESISTANCE		NO. OF CONDR.	DEFLECTION AFTER 1 MIN.	INSULATION RESISTANCE	
		ABSOLUTE	PER MILE			ABSOLUTE	PER MILE
1				52			
2				53			
3				54			
4				55			
5				56			
6				57			
7				58			
8				59			
9				60			
10				61			
11				62			
12				63			
13				64			
14				65			
15				66			
16				67			
17				68			
18				69			
19				70			
20				71			
21				72			
22				73			
23				74			
24				75			
25				76			
26				77			
27				78			
28				79			
29				80			
30				81			
31				82			
32				83			
33				84			
34				85			
35				86			
36				87			
37				88			
38				89			
39				90			
40				91			
41				92			
42				93			
43				94			
44				95			
45				96			
46				97			
47				98			
48				99			
49				100			
50				101			
51				102			

NO. OF CONDR.	DISCHARGE AFTER 15 SEC.	INDUCTIVE CAPACITY	
		ABSOLUTE	PER MILE

NO. OF CONDR.	READINGS	CONDUCTOR ABSOLUTE	RESISTANCE PER MILE

SUMMARY

	ABSOLUTE	PER MILE	HIGHEST	LOWEST
INS. RESIS.				
IND. CAP.				
COND. RES.				

CONDUCTORS OPEN

GROUNDED

CUT IN

REMARKS

DATE

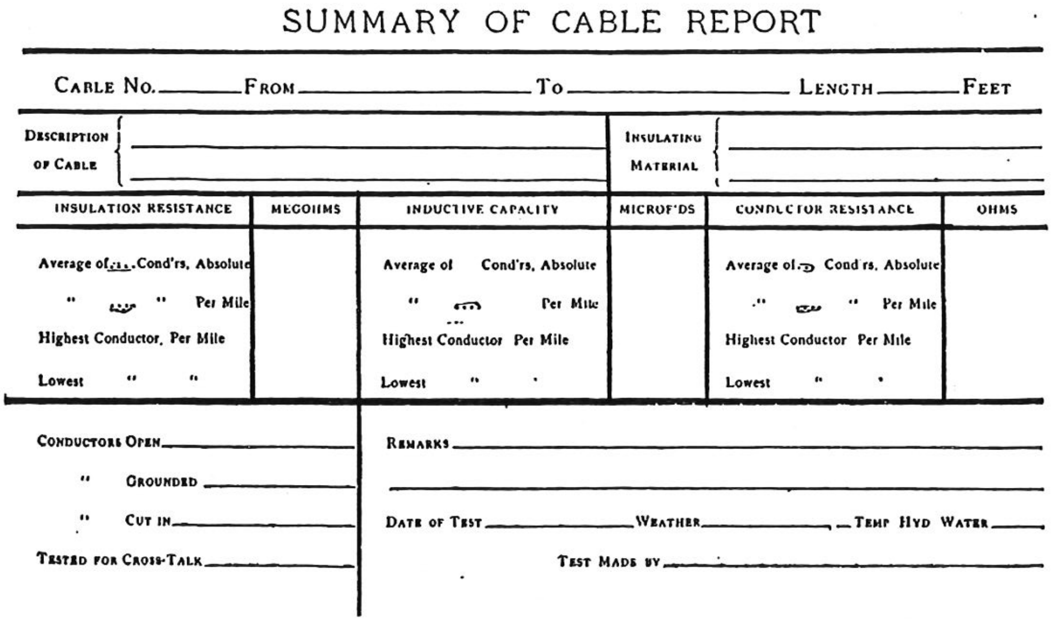
WEATHER

TEST MADE BY

(FIG. 37.)

bottom of the sheet spaces may be ruled for the summary of average results, general remarks, date and weather, and name of observer.

The accompanying forms show, first, a full test-sheet for recording the test on a telephone cable, containing fifty-one pairs of wires, that being the type of cable generally adopted by telephone companies using underground systems; and second, a summary of the test for furnishing a report to the executive department on the general condition of a cable. (Figs. 37 and 38.)



SUMMARY OF CABLE REPORT

CABLE No. ______ FROM ______ TO ______ LENGTH ______ FEET

DESCRIPTION OF CABLE ______

INSULATING MATERIAL ______

INSULATION RESISTANCE	MEGOHMS	INDUCTIVE CAPACITY	MICROF'DS	CONDUCTOR RESISTANCE	OHMS
Average of Cond'rs, Absolute		Average of Cond'rs, Absolute		Average of Cond'rs, Absolute	
" " Per Mile		" Per Mile		" " Per Mile	
Highest Conductor, Per Mile		Highest Conductor Per Mile		Highest Conductor Per Mile	
Lowest " "		Lowest "		Lowest "	

CONDUCTORS OPEN ______

" GROUNDED ______

" CUT IN ______

TESTED FOR CROSS-TALK ______

REMARKS ______

DATE OF TEST ______ WEATHER ______ TEMP HYD WATER ______

TEST MADE BY ______

FIG. 38.

In the heading of the test-sheet are left spaces for the number, description, route and length of the cable. Below this are entered the galvanometer constant and discharge from standard condenser, spaces being left to fill in the number of cells, high resistance and shunt used and the capacity of condenser and battery power employed in taking the discharge. The particulars of the lead are noted here, and in cases where a long lead is used, it would be useful to enter the discharge from the lead before connecting on the cable for capacity test. The rest of the sheet explains itself, the vertical columns being ruled for entering the readings in each test and the results, absolute and per mile, in megohms, microfarads and ohms. The summary at the bottom of the sheet is a useful addition, as it shows at a glance the general condition of the cable. The figures entered in the summary are transferred to the second form, "summary of cable report," when it is necessary to report a test to some department other than that in which the full records are kept. The permanent record book is ruled in an almost precisely similar manner to the test-sheet used for noting down the observations at the time the test is made, with the exception that the summary is transferred to the heading.

In designing test-sheets for use in cable factories, or for testing single wires, such as electric light cables or overhead wires, the sheet can, of course, be made much smaller, but it will be found a good plan to use a heading, similar to that described above, giving all the details of the cable itself and of the constants used in working out the test, otherwise the records will be incomplete and unsatisfactory.

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